A CENTURY OF PROGRESS

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Presented to my good friend
Frank DeWolf
with the author's sincere regards
W O Hotchkiss

A CENTURY OF PROGRESS SERIES

A series of volumes by well-known scholars presenting the essential features of those fundamental sciences which are the foundation stones of modern industry

A CENTURY OF PROGRESS SERIES

THE STORY OF A BILLION YEARS

BY

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Michigan College of Mining and Technology

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TO

EDITH AND NANCY

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PREFACE

A GREAT exposition to celebrate the completion of a Century of Progress is being prepared for us in Chicago. In this past century geology, like all other sciences, has developed from the most meager of beginnings to its present highly useful state. Science, like the city of Chicago, has grown in this hundred years of progress from almost nothing to superlative greatness.

It has been a pleasant task to prepare this volume and thus to make my contribution to the efforts of scientific men toward promoting a better understanding of the part science plays in our great civilization. A proper understanding of geology and of the great lessons it teaches means much to each of us as intelligent citizens. It also adds much to our pleasure by satisfying in some degree the curiosity concerning his ordinary surroundings which possesses every active-minded person.

While the writing of this volume has been pleasant, I cannot claim that it has been easy. To sketch the events of a billion years in so small a compass requires the most careful selection of sub-

jects for presentation and the leaving out of a much larger number that I should like to include. I can only hope that in my selection I have succeeded in giving a picture of these events that is well balanced and interesting. If I have been even moderately successful, I am well satisfied. In the attempt to accomplish this purpose I have been fortunate in having the helpful criticisms and constructive suggestions of many friends. Among these are members of the faculty of this college, Dr. E. L. Wood, Professors C. H. Baxter, James Fisher, C. M. Carson, T. M. Broderick, and L. A. Rose. I am also deeply indebted to the Rev. Cowley-Carroll, Judge John G. Stone, Miss Annette Sibilsky, Miss B. J. McMahon, and my wife and daughter who have criticized the manuscript, as well as to Mr. J. T. Reeder for some of the photographs from his excellent collection, and to the American Museum of Natural History for the photographs of the Coal Age forest and the Thunder Lizards.

William Otis Hotchkiss.

Michigan College of Mining and Technology,
Houghton, Michigan,
August, 1932.

CHAPTER I

GEOLOGY, THE EASY SCIENCE

WHEN the average intelligent person hears science mentioned, he thinks of it as something outside his daily affairs, something difficult, mysterious, and even quite beyond his understanding. His impression is true only for the more advanced and specialized parts. It is not at all true for the great fundamental ideas and principles of science. These can be understood by the high school graduate; they apply to the things with which he comes in daily contact.

In order to brush away the veil of mystery that too often surrounds science, we need to have these fundamental ideas and principles stated in familiar terms. We need to have explained to us, in words from our own vocabulary, that science is merely the statement of the orderly relations between facts, many of which each of us knows or can readily know from common-sense observations of the everyday things about us. Once this explanation is made, we are able to understand causes and effects, so that things begin to appear to us in delightfully simple and orderly relations and not

as an appalling number of independent facts each of which must be separately mastered.

It is true that in geology, as in other sciences, there are mysteries and things difficult to understand. Fortunately these need not concern us greatly because most of the important facts are easily understood. All that need be done in order to give us a very satisfying knowledge of things geological is to call them to our attention. Geology concerns itself with the familiar hills and valleys, rivers and lakes, mountains and plains that surround us. It concerns itself not only with great wonders far away, but also with the small intimate things we can see in our own neighborhood if our eyes are open.

One of the most enlightening things in the study of geology is the attainment of an adequate understanding of the vast time it has taken nature to write the record we see in the rocks. You and I live our lives in small units. When we were children, a quarter of an hour often seemed too long to be endured, particularly when we waited impatiently for the close of school or the start for a picnic. We measure our ordinary movements and the things close to us in feet and inches, in hours and minutes, in pounds and ounces. Because these units measure our daily activities and near surroundings, we have a fairly definite notion of

what they mean. When we begin to group them into larger units and try to think in terms of miles and tons and years, our notions become less accurate. When we multiply these familiar units to describe a country, a mountain, or the life of a nation, the definiteness of our ideas fades and they become vague.

Among time-units the longest we can understand from personal experience is our own life span. It is not surprising, then, that we can have no really accurate idea of so long a period as a century. If we think of the six or seven thousand years of recorded history, its beginnings seem incredibly far back, farther back than any of our familiar units will permit us to measure understandingly. When we try to imagine such a vast stretch of time as a billion years, the units we ordinarily use are so absurdly small that they afford us no useful comparison. We must resort to other comparisons to get any kind of picture at all. Let us imagine a man so small that he has to take sixteen steps to go one inch, and so slow that he can take but one step a year. If he lived in New York and wanted to walk to the Exposition in Chicago he would have had to start a billion years ago.

In this story of the billion years of the existence of our earth, the tremendous length of the time

involved is one of the ideas we find hard to grasp. Another is the number of things that can happen—even at a slow pace—in a billion years. At the rate of movement of our imaginary small man—one-sixteenth of an inch a year—a mountain range as high as the Rockies could be raised from sea level and lowered back to sea level one hundred and sixty times. A billion years has afforded time for the earth to go through many cycles of changes of great magnitude, and to do so in most leisurely manner. There has been time for the slow, unhurried development of the almost infinitely varied forms of vegetable and animal life. The days of creation have been long and well filled with labor. Well might the ancient Hebrew prophet say, "He stood, and measured the earth; . . . . and the everlasting mountains were scattered, the perpetual hills did bow: his ways are everlasting." We can see the labors of creation continuing before our eyes, if we can but enlarge our mental time scale to permit us to see present events in their true relation to those of long ago.

THE STORY OF A WISCONSIN MILL POND

Geology, in its efforts to bring this long time and its multitude of happenings into understandable scale, has found the year and the century too short to use as time units. It has grouped the

past into larger units—into great cycles of similar events—so that our minds can picture them more readily.

To show you how these large group units are selected, I want to tell you the story of a Wisconsin mill pond that I once studied for a few interesting hours. This pocket edition of a geologic epoch began with an unusual event in the history of a stream—the building of a dam. It was ended by another unusual event—a flood that destroyed the dam, and cut a tiny canyon through the sediments deposited in the pond. Such epochs, on a vastly larger time scale, measured by the deposition of hundreds or thousands of feet of sediments, are used as units in the story of the billion years of the history of the earth. They begin with an unusual event, the depression of a large area below sea level. They endure millions or tens of millions of years, during which events are infallibly recorded in the sediments. They end with another unusual event—the elevation of the area above the sea and its subjection to the action of the wind, of the rain, and of the streams, which gradually wear it away.

As I looked at the vertical sides of the three-foot "canyon" cut in the sediments in the Wisconsin mill pond, I could see the edges of thin horizontal layers of different kinds of mud. Closer

examination showed that some of these layers were of coarse material and some of fine, that some were light colored and some dark. Some contained decayed leaves and other vegetable matter. By careful observation I could distinguish the layers that represented a year's deposit. Counting these annual layers told me that they had been accumulating for about seventy years. Information from neighboring farmers to the effect that the dam had been built seventy years before checked my observations most satisfactorily.

The alphabet of this story is simple. The little stream carried mud and sand, as all streams do. It carried fallen leaves in the autumn. It carried more mud and sand and more coarse material in flood times than in dry times. When it reached the still water of the pond, the sand and mud and even the leaves finally settled to the bottom, so that the water which escaped over the dam was much clearer than that which came into the pond. The coarser sand and small pebbles settled much more quickly than the fine mud.

With these simple every-day facts as an alphabet I was prepared to read the story recorded in the mud layers behind the old dam. A thick layer of sand and fine pebbles told of a long-past flood stage in the little stream. When, over that layer, I found a layer of the finest mud, I knew that the

flood had subsided. A layer which contained leaves in fair abundance enabled me to deduce with Sherlock Holmes certainty that it must have been deposited in the autumn. When I found these leaf-bearing layers separated by thin layers of fine mud, I knew that there had come a period of dry years without heavy rainfall and floods; and when I found the leaf-bearing layers separated by thick beds of coarser-grained material, I was certain that they represented a period of years of heavy rainfall during which the stream was more often in flood. In this way I could identify both the dry years and the rainy years. If I had desired, I could have checked my conclusions by the local weather records. I could have checked them also by cutting a large tree nearby and observing the layers of annual growth. Wet years would have been represented by thick layers and dry years by thin. By a similar study of the annular rings of growth in the old trees of California and other places the weather records have been traced back beyond historical times. Thus, with satisfactory accuracy the climate of California in the time of Christ can be compared with that of the present.

DeGeer, studying the mud and sand deposits in ancient Swedish lakes, found that the climate had left a continuous record for the last eight thousand

years, so that it is possible to tell with quite pleasing accuracy the various "spells of weather" which marked that long stretch of time.

The story of the mud layers in the Wisconsin mill pond illustrates perfectly three of the great fundamental principles of geology. The stream that flowed into the mill pond was typical of all streams, big and little. It carried mud and sand and pebbles with it in its flow. It deposited this material when its rapid flow was stopped in the mill pond. When the flood came that broke the dam, this deposit in the pond again started on its way toward the sea, to be redeposited in the next quiet water, and so by successive steps finally to be carried to the Gulf of Mexico and find a resting place in the sea.

The material carried into the mill pond had been washed from the adjacent hillsides into the stream by the rain, a process called "erosion." Any sand bank or rivulet shows this process at work. It is the process which carved the magnificent gorge of the Grand Canyon, but it is not different from the process you can see going on in your back yard during a shower or when the garden hose is at work.

The other fundamental principles learned from the study of the mill pond stream are known as "transportation" and "deposition." The stream

transported the mud washed into it and, acting on the third fundamental principle, "deposition," deposited its load when it reached quiet water.

Erosion, transportation, and deposition are three fundamental geologic processes which we can see at work all about us. If with these processes in mind we look through the eyes of a billion years, the "everlasting hills" become only the uneroded remnants of hills once larger and different in shape. The pleasant valleys we love to look upon were once smaller and of different form.

Erosion and transportation are bit by bit continuously carving the face of the earth into new forms. Those who see and understand take delight not only in rebuilding in imagination the forms that have been worn away but also in picturing in the mind's eye those forms that natural processes will develop in the future.

THE DISCOVERIES OF A SCOTCH FARMER

It is hard for us, with the freedom of thought we enjoy today, to understand the attitude that prevailed no longer than a century ago. Men were more intolerant. The traditions and beliefs handed down from previous generations were respected to a superlative degree. If a fact of nature clashed with tradition, it was just too bad for the fact and also for the man who, discarding

the tradition, believed in the fact. Anyone who deliberately set out to study natural phenomena ran the risk of being regarded as in league with the devil; he was likely to be ostracised by his friends and stood in grave danger of death from his enemies.

Respect for tradition and for the authorities of the past is an age-old characteristic of the race, and man's reluctance to replace it with respect for demonstrated fact must not be considered wholly a bad thing. We know that for their own good, men who reverence only that which they do not understand, the mysterious, and what they consider supernatural should not be deprived of that reverence until it can be supplanted by the deeper reverence which comes from fuller understanding.

In view of the strong hold that tradition has on our thoughts, even today, it is not strange that the simple processes of erosion, transportation, and deposition, so clearly observable in the Wisconsin mill pond, were not understood even by the most advanced scientific men much over a hundred years ago.

It was reserved for a Scotch farmer, a retired physician named Hutton, to see them in their true nature and in all their vast significance.

We can picture him in his strolls along the sandy

beaches of his sea-coast farm. At his right was the water with its ceaselessly active waves; at his left were cliffs of sandstone and limestone in alternating beds. On a quiet day the waves contented themselves with making beautiful ripple marks on the sandy beach. On rough days they beat wildly at the cliffs and tore them into fragments, which were worn into pebbles and sand grains and added to the beach.

In imagination we can walk along with him and admire the sculpture of the ripple marks just below the water's edge. When we come to a fresh slab of sandstone, beaten from the cliff by a recent storm, and find that it shows the same beautifully carved ripple marks which we see in the loose sand of the beach, we can take with him the first simple step toward a great discovery. We can conclude (as he did) that the ripple marks on the sandstone block must have been made by the waves on a beach of some long gone age. We can clamber over the cliffs and find all though the sandstone other ripple-marked beds that had been buried by the sand of succeeding beds and thus preserved for us to see. Next we can conclude that the shore on which this sandstone was being deposited must have been sinking land and that each rippled beach was covered by the later ones deposited over it. It then becomes obvious that later on

these old beach sands must have been raised above the sea and hardened into sandstone, only to be attacked by the waves of the present day and partly worn away, the remainder being left as the present cliffs.

Finally, we can go over in our minds the full cycle of events: (1) fresh beach sands being deposited on a sinking shore; (2) this sand deposit being raised above the sea and cemented into sandstone; and (3) the sandstone then being attacked by the waves and worn down into sand to build a new beach. These are the familiar principles seen in the Wisconsin mill pond: (1) *deposition* and raising and hardening; (2) *erosion* by the waves; and (3) *transportation* along the beach.

As our Scotch farmer gradually reached the fullness of these conclusions—and such conclusions do not come so quickly as they are pictured above, but only by slow, logical analysis and anxious, careful thought—he could look back into the past and imagine a numberless succession of such cycles of erosion, transportation, and deposition. He could picture the cliffs on innumerable successions of beaches in bygone ages being worn down, transported by the waves, deposited on the beach, and raised up above the sea, only to repeat the cycle. He could turn to the future and see

Fig. 1. Sandstone cliff on Lake Superior near Houghton, Michigan. This cliff shows layers of different character much like those which led Hutton to make his great discovery or those deposited in the Wisconsin mill pond. The coarse blocks at the shore line are in process of being broken into sand grains by the waves to build the present beach on which the photographer stood. Photograph by J. T. Reeder.

the present rippled beach sands under his feet raised above the sea, hardened into rock, and again eroded into cliffs, in endless successions of this cycle. Small wonder then that he wrote, "I see no vestige of a beginning, no prospect of an end." There must have come to him at that time the vision of the vast sweep of the ages which go to make up the story of the billion years of the earth's history. His simple but epoch-making discoveries started geological science on the way to reading that history in the rocks.

The great discoveries of science, once made, appear so simple that they are almost disappointing. A Franklin flies a kite and finds that lightning is the same as electricity. A Faraday, moving a boy's toy magnet, finds that an electric current is produced in a nearby wire, and his simple discovery becomes the foundation of our whole electrical industry. When he was rather scornfully asked by a legislator as to the usefulness of his discovery (which was at once recognized as a great scientific principle) Faraday testily replied, "Perhaps you can tax it some day." And the legislators have.

Our Scotch farmer, Hutton, probably would not have dared even to suggest that the consequences of his discoveries would ever be of material use to mankind; much less would he have had the

temerity to suggest that they might some day be taxable. But out of them grew the long continued series of geological observations that have helped us find and use the tremendous wealth of mineral resources which make living conditions in our generation so different from those of a hundred years ago.

Hutton studied the cliffs and noted the succession of beds of different kinds of sandstone and limestone lying one upon another. He crossed a small stream and found that the cliffs on the other side showed the same layers in the same order, and he then concluded that these beds of rock must once have been continuous between the cliffs, for the old beach and sea bottom deposits could not have been built up in separate hills as they now appeared but must have been continuous like the present beach. He watched the stream in the valley between the cliffs and noted that it was slowly but unceasingly carrying its load of sand and mud from the valley sides into the sea. He studied the little branch valleys and depressions and found that, even though no water was then flowing in some of them, each one carried unmistakable evidence that a rivulet flowed in rainy weather—a rivulet that did its allotted share of work each season in carrying material from along its course into the main stream. So it gradually

became certain, as his studies continued, that the whole valley had been carved by the processes of erosion and transportation which he could see in slow but unremitting operation all about him.

The difficult thing to picture was the vast extent of time required to remove the enormous amount of material which once had been where the valley now lay. The change observable in a man's whole lifetime was exceedingly small compared to the total change that Hutton could see must have taken place. And yet here were the processes slowly at work, and here was the result. There was no escaping the conclusion that the processes *must have worked long enough to produce the result.* Truly, in the millions of years that go to make the billion and more of the story the rocks tell us, there must have been ample time for many cycles of this kind. There must have been time for many valleys to have been carved in uplifted sea deposits—time for many long, slow, alternate uplifts and depressions of the places where most of us live, so that under our feet and in the hills about us are the records of periods of alternate sea and land, of deposition and erosion, many times repeated.

CHAPTER II

THE SURFACE FEATURES

THE LARGER FEATURES

If our sense of time were so different that to us "a thousand years is as one day," we would not use the expression "old as the hills" as a simile for the superlatively ancient. We would realize easily, as we do now with effort, that our hills are constantly being eroded away and cut down. If our senses were more finely fashioned, we would know as a matter of everyday experience that our "solid earth" is aquiver with extremely rapid movements of a great variety. As it is, we know this chiefly from delicate instruments. If, again, "a thousand years is as one day" were the pace of our senses, we would know from daily experience that the earth's surface, which we now think of as our best example of stability, is undergoing slow movements, upward in some places and downward in others, that take many thousands of years to complete. But as it is, we must let our delicate instruments and our long continued observations

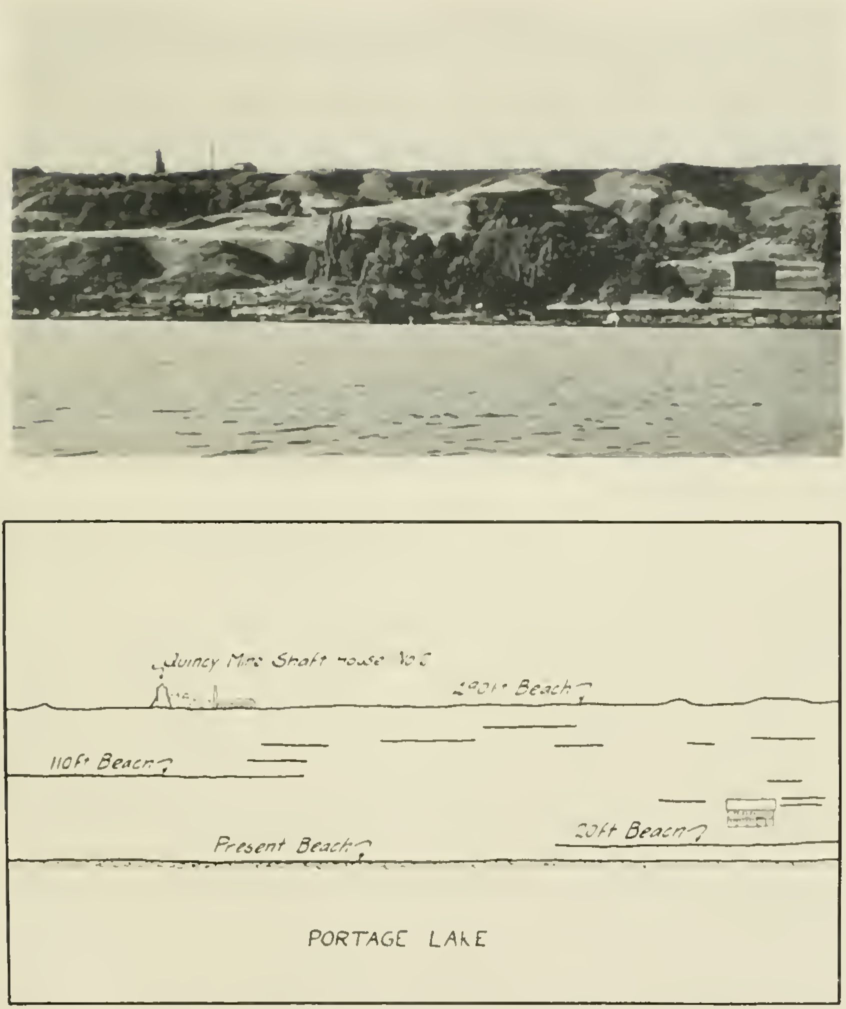

FIG. 2. Ancient beaches on the banks of Portage Lake opposite the Michigan College of Mining and Technology. These beaches are the product of former higher stages of Lake Superior. The sky line, on which appears a copper mine shaft house, is an old beach about 490 feet above the present lake level. Several other beaches are seen at lower levels. The horizontal lines on the drawing will help you to pick out the more noticeable of them. Photograph by J. T. Reeder.

interpret for us the things we are not attuned to see or feel.

With precise instruments we can detect the vibrations due to an earthquake at the opposite side of the earth, or we can measure the actual depression of the land along a sea coast produced by the added weight of water at high tide. Careful observations have shown that there is a "body tide" in this "solid earth" of ours that raises and lowers the surface at Chicago a few inches twice a day. Like the tides of the sea it is caused by the attraction of the moon.

There is equally convincing evidence that slow movements, taking many centuries or even millions of years to complete, have taken place in the past and are now going on, though we cannot directly observe any such movement even with our most accurate instruments.

Around the shores of the Great Lakes are beaches which were formed after the great glaciers melted away, as described in Chapter VII. These beaches must have been formed horizontally at water level. Now, perhaps 20,000 years since they were formed by the waves, we find them tilted southward, some of them as much as eighty feet in one hundred miles. The northern part has been raised that much above the southern part. The fact that this area was once covered with a great

FIG. 3. The present outline of North America is the heavy line. If the continent were to sink 600 feet, the sea would come over the lowlands and cover the horizontal lined area inside the present outline. If the continent were to rise 600 feet, the sea would retreat to the outer edge of the horizontal lined area and all that area would be dry land.

ice sheet which weighed it down with many hundreds of tons per square foot points logically to the conclusion that because of the melting away of this load the land has risen and in rising has tilted toward the south.

The great fertile areas of gently undulating land on which most of the human race dwells are the sea bottoms of former times. Some of these areas rose from the sea hundreds of millions of years ago; some only a few million years ago, "just recently" on a geologic time scale.

The rocks we find in rich, thickly populated regions are usually the flat-lying sandstones, limestones, and shales that are typical of sea bottom deposits. In mountainous regions we generally find both igneous rocks—rocks that came from within the earth in a molten condition—and the familiar sea bottom deposits. Here, however, the rocks of the old sea bottoms have usually been tilted up steeply and are on edge or even overturned, a condition which proves that the movements in mountain areas have been more extreme.

The changes in outline and area of North America that would result from its sinking or rising 600 feet are shown in Figure 3. The heavy line shows the familiar shape of our continent as it is today. The shaded area inside this outline would be submerged if the continent sank 600 feet.

The sea would come up the Mississippi valley almost to Chicago. The warm waters of this enlarged Gulf of Mexico would furnish a good heating system to warm the climate of the Illinois-Ohio region and make it more like the Florida of today. The river valleys would make a system of gulfs and bays and estuaries, much like Chesapeake Bay in appearance but on a larger scale. The Hudson river valley would be a strait separating the New England island from the mainland. Florida and the whole of the Atlantic and Gulf coasts would again become sea bottom, on which the waters would begin to deposit sands and clay and lime mud as they have in the past.

If the continent were to rise 600 feet, the shaded area outside the heavy outline in Figure 3 would become dry land. Florida would become a wider peninsula. A large island would appear off its east coast. Chesapeake Bay would become dry land, and the sea shore would lie about one hundred miles east of most of the present coast line all along the Atlantic sea board. The Great Lakes would speedily be emptied except for remnants of Lake Superior and Lake Michigan. Hudson Bay would be a great flat plain with the few large lakes shown by the white areas.

The familiar surface and form of our continent would be thus radically changed by such relatively

small movements as a 600-foot rise or fall. I refer to these movements as relatively small because they could be accomplished in a period fairly easy for us to comprehend. The coast of northern Sweden is known to be rising at the rate of six feet in a hundred years, though to our observation it behaves in every respect like our familiar "solid earth." At such a rate either of the changes shown in Figure 3 could take place in a hundred centuries, less than twice as long as men have been recording history. Such movements and changes are going on constantly, slowly, unobserved, in the same manner today as the evidence in the rocks shows us that they have gone on throughout the billion years of the earth's history.

The reason for these changes we do not know in detail. The only thing we know is that they are primarily due to the force of gravity. The planetesimal theory of the origin of the earth, discussed in Chapter III, requires that the earth originally must have been a mixture of all kinds of materials, unevenly distributed masses, large and small, of heavy and light planetesimals. The tendency of heavy materials is to sink and thus force the lighter materials up, just as a brick laid in a pan of dough slowly sinks and bulges up the dough around it. We know that the rocks of the deep ocean basins are, in general, heavier than those of

the continents and shallow seas. The patient, slow adjustments of these heavy and light masses have been going on all through the long past, and will undoubtedly continue for long geologic eras in the future until final equilibrium is reached. To them we can attribute the great surface features of the earth, the continents and the ocean deeps, the mountains, the plateaus, and the lowlands. Because of them we must look upon this planet of ours not as the solid unchangeable thing which our short personal experiences would lead us to consider it, but as a moving, weaving, breathing, progressing thing. The surface of the earth is not now exactly like it ever was before, and it has today a set of features different from those it will have in geologic periods of the future.

THE SMALLER FEATURES

In our ordinary travels, as we walk or motor about, the most common feature about us is the familiar soil. It is so common that we seldom think of it. Rarely do we see a quarry or a cliff of rock in the great plain areas where many of us live. Accordingly, some of us think of "earth" or soil as the material of which the whole earth is made. It is only when we seek the acquaintance of the well driller or the miner that we learn that our "earth" is usually only a few feet in thickness

—rarely as much as a hundred feet. Everywhere beneath our familiar "earth" we find solid rock if we drill down a short distance.

So let us turn for a short time from the grand surface features of the earth to the more intimate features—from continents and deep seas, mountains and great plains, to the rocks and soils that we find all about us.

If we study the rocks that we most commonly see, we find them to be made up of the débris of earlier rocks, just as the Scotch farmer, Hutton, found his beaches being built up from the sands derived from the breaking up of the rocks of the sea cliffs. The only rocks most of us find in our own neighborhood are sandstones, shales, and limestones, rocks that are produced by the hardening and cementing together of sand, clay mud, and lime mud. All of these are called *sedimentary* rocks; they comprise one of the two great primary classes into which rocks are divided.

If we trace the history of the individual grains of which the sedimentary class of rocks is composed, we find that they all came originally from the other great class of rocks which, likewise named from their method of origin, are known as *igneous* rocks. This class includes lavas, granites, and many other kinds of rocks, all of which have solidified from a molten condition. These igneous

rocks are almost always harder than *sedimentary* rocks.

All rocks, whether igneous or sedimentary, are slowly but constantly undergoing alteration and change. Those exposed at the surface are subject to the processes of weathering and erosion.

It seems strange to us to think of the solid rocks as being soluble in water; yet, in the "time enough" which the billion years of the earth's story gives, practically all the constituents of rocks are slowly dissolved by water. Some constituents are dissolved to a slight extent only and even then very slowly. Others are dissolved with relative rapidity. It has been computed that in the Appalachian mountains the solution due to rainfall will in a year carry away 275 tons from each square mile. This is a large amount, but if we reduce it to more familiar units we find it is less than one-third of an ounce per square foot of surface per year. If we analyze the waters of our rivers, we find that they carry tremendous tonnages of dissolved material to the sea each year. Careful studies of the Mississippi river indicate that each year it carries 113 million tons of dissolved rock material to the sea.

The weathering of rocks is due in part to the solvent action of the water which seeps through them. It is due also to the effect of wind, of tem-

perature changes, and of vegetation. In desert regions the wind is very active in wearing away the hardest rocks and carving them into fantastic shapes. Changes in temperature from winter to summer, from hot mid-day to cool night cause expansion and contraction that break the exposed rocks. The freezing of water in crevices slowly wedges the broken fragments apart. Tree roots growing in cracks aid in the process of breaking up the rocks.

The net result of solution, wind, temperature changes, and vegetation is to disintegrate all rocks; therefore in looking about us we find that almost the whole surface of the earth is made up, not of solid rock, but of the products of rock weathering which we know as soil or "earth." This loose soil, since it is readily eroded by wind, rain, and streams, is constantly being carried away. On steep slopes it is removed as fast as it forms; there we find bare rocks. On gentler slopes and plains it is formed by rock decay or deposited by wash from the hills approximately as fast as it is removed; so there we find the great fertile areas that furnish food and clothing for mankind, and there live the greater numbers of the race.

The Mississippi river not only carries vast quantities of rock material to the sea in solution; it carries much greater quantities of undissolved

materials such as mud and sand. It has been estimated that in one year the mud and sand thus carried to the sea amounts to over four hundred million tons—enough to cover the loop district in Chicago to the top of its tallest buildings. The rock material which this river carries in solution and suspension is sufficient to lower its whole valley one foot in three thousand to four thousand years. At this rate the whole continent could be reduced to sea level in about seven million years.

From the products of rock decay thus carried to the sea come the salt and lime that we find in solution in sea water and the sands and muds that we find in the great deltas, along the coast, and on the adjacent shallow sea bottoms. These will be hardened into rock, will be raised above the sea, and then will go on anew through repeated weathering and erosion cycles in future geologic periods. As Hutton said, we can see "no vestige of a beginning, no prospect of an end."

Deeper beneath the surface of the earth, where every opening in the rocks is filled with water, we find a different process at work. There the water becomes saturated with dissolved rock material which it readily deposits in favorable places. The re-deposition of this dissolved rock material results in cementing our sands and muds into solid rock.

If we were to go down several miles into the earth, we would get into the regions where pressures are great and temperatures are high. There we would find that the materials of the solid rocks re-crystallize and re-combine into different minerals. In these deeper regions arises a third great class of rocks, altered rocks, to which we give a Greek name, "metamorphic," meaning changed in form. Both sedimentary and igneous rocks which have been buried many thousands of feet are sometimes re-crystallized and changed so completely that we cannot tell their original nature when they are later exposed at the surface by elevation and erosion. By this process of metamorphism limestone becomes marble, sandstone becomes quartzite, and other kinds of rocks are greatly changed. The Michigan, Wisconsin, and Minnesota region around Lake Superior, northern New York and New England, and a large part of central Canada are composed in large part of very ancient metamorphic rocks.

EARTHQUAKES AND VOLCANOES

Earthquakes and volcanoes are unusual and violent episodes in the history of the earth. They attract much greater attention than vastly more important events that take place quietly and unobtrusively. They furnish outstanding exam-

ples of the effect of advertising. The things they do are done suddenly and even explosively in a way that demands and gets the attention of the whole world. The Mississippi river carries to the sea more material in a year than a volcano may throw out in a century. The river, however, does its work continuously and quietly and attracts little attention; the volcano does its whole century's work in a few hours with a lot of fuss and noise and arouses universal interest.

Volcanoes and earthquakes play a part in the life of the earth somewhat similar to the part that boils play in the life of a person. Both are "skin eruptions" that are painful and focus our attention on them most intensively for a short period but are soon forgotten.

Wherever men have dug deep into the earth in mining or in drilling for oil, they have found that the temperature of the rocks increases as they go deeper. In some regions the temperature of the rocks rises 1°F. for each 20 feet of increased depth. Here the rocks at the bottom of a 1000-foot vertical drill hole would be 50°F. warmer than at the surface. In other regions we find the temperature rises 1°F. for 130 feet of increased depth. Here we would find the rocks at the bottom of a 1000-foot drill hole only about 8°F. warmer than at the surface. The average over the world is 1°F. for

each 60 feet. It is believed that at depths of twenty to thirty miles the rocks are so hot that they would melt if they were at the surface. However, since rocks expand on melting, the great pressure of the overlying rock is usually sufficient to prevent them from becoming molten. If by the great slow movements of the earth's surface the pressure on these hot rocks is sufficiently reduced, they can expand and melt and find their way to the surface. The expanded molten rock is lighter than the unexpanded, unmelted rock surrounding it. At depths of only a few thousand feet the pressure is great enough to cause solid rocks to flow slowly, much as you have seen a barrel of solid asphalt slowly slump down when the support of the staves is taken away. The rise of the molten rock to the surface is not at all rapid. It takes place much as a drop of oil rises in water—because the surrounding material is heavier and, squeezing in beneath it, forces it upward. As it nears the surface where the pressure becomes less, the gases which are always included in the molten rock can begin to escape. The heat evolved from the action of these gases helps to keep the molten rock hot and fluid. When the surface is reached, the gases escape with violence and produce the glorious, brilliant, terrifying phenomenon that we call a volcanic eruption.

The gases associated with an eruption are chiefly steam and compounds of hydrogen, carbon and sulphur, with minor amounts of chlorine, nitrogen, and argon. It has been estimated that the actual weight of gases given off in a volcanic eruption is many times as great as the total weight of lava and ashes extruded.

Sometimes lava is forced out of the volcano during an eruption and forms lava flows; sometimes it remains within the volcano and cools and solidifies there. It fills cracks and fissures that open in the rocks and produces what we know as intrusive dikes. Sometimes the molten rock will squeeze in between layers of sedimentary rocks and so make what is called a sill.

It is apparent that volcanoes are found where the cool outer part of the crust of the earth is abnormally weak or thin. There is a great chain of them surrounding the Pacific Ocean. This volcanic belt is also the most active earthquake belt. Volcanoes and earthquakes occur together because of the weakness of the crust. Not only do the actual eruptions of volcanoes cause tremendous readjustments in the rocks, but the great strains, due to all the differences in temperature and in weight of the rocks below the surface, find their easiest relief at these weak zones. Along such zones of weakness the rocks are broken,

great cracks and dislocations are developed, the rocks are slowly squeezed up and tilted, and mountain ranges result.

The slow uplift causes tremendous strains in the rock. When these strains become great enough to overcome the strength of the rocks, a sudden break occurs. Earthquakes are the jars caused by such breaks. Fortunately most of them are mild tremors that cause little or no damage. But once in a while a shock will be great enough to shake down buildings and result in great loss of life and property. Earthquakes that occur off shore under the sea bottom sometimes cause great tidal waves that rush upon the shore and engulf thousands of people.

Fortunately, major disasters due to volcanic eruptions and earthquakes rarely enter into our personal experience. The internal adjustments of the earth take place slowly and quietly enough to justify our continuing to call it a good old "solid earth."

CHAPTER III

THE ORIGIN OF THE EARTH

The planet on which we live has long been the subject of speculation and study by thoughtful men. The study of what it is like and its relation to the heavenly bodies—the sun, moon, and stars—has resulted in many different and progressively more accurate notions throughout the historical record. As observations and knowledge increased, it was discovered that the earth is not the center and master of the heavenly bodies, but that it revolves about the sun. It was also found that the heavenly bodies could be divided into three different classes—the "fixed stars," that seemingly hold their place in the heavens throughout the years; a group of other stars that, like the earth, revolve about the sun and so change their places in the sky and move with respect to the fixed stars; and the sun and moon, the two greatest heavenly objects from man's viewpoint. The moving stars were called planets, a word meaning literally "wanderers." All the heavenly bodies were found to move in regular and orderly manner. Thus the idea of

the universe developed from that of a non-understandable chaos to that of an orderly system with unchangeable laws governing every movement that could be seen.

With the great increase in the knowledge of natural sciences, which began not much over a century ago, these laws of the universe came to be understood sufficiently well for scientists to construct theories of the past history of the solar system. The most satisfactory was that of La Place, a French astronomer. According to his theory, the solar system was first a single rotating ball of fiery gas extending out beyond the orbit of the farthest planet. Gradually the gas cooled and contracted. As it contracted, its speed of rotation so increased that the centrifugal force equalled that of gravity and successive rings of gas were left behind. According to La Place, each of these rings gradually collected to make a planet. This cooling and contraction have continued to the present time and resulted in the sun's reaching its present size, with a family of planets revolving about it.

According to this theory, our earth reached its present stage by cooling from a ring of fiery gas in which there were two nearby knots about which the cooling gas ring collected to make the earth and the moon. These gradually cooled and con-

tracted, first to molten globes and finally to the condition in which we know them. This theory has resulted in the common impression that the solid surface on which we live is but a relatively thin crust over a still molten interior. It pictures a gradually cooling solar system headed for an ultimate cold and dead condition in which the heat of the sun would be finally exhausted, all the seas would be frozen solid, and our earth would become too frigid to be the habitation of living beings.

Cardinal Newman once stated that his church in its development had proved its essential truth by its genius for change and its capacity for adjustment to meet altered circumstances. He said, "In a higher world it is otherwise, but here below to live is to change, and to be perfect is to have changed often." This thought is true of other things as well. As knowledge increases, old theories, scientific, political, economic, as well as social and religious conceptions, must be altered, discarded, or replaced to fit an advanced state of knowledge if human institutions and welfare are to make proper progress.

At the end of the last century a famous geologist, T. C. Chamberlin, set out to find the cause of the great ice age described in Chapter VII. Geologists in their travels over the earth had recently

found evidence of several glacial periods. One occurred perhaps seven hundred million years ago, one about five hundred million years ago, one about two hundred million years ago, and finally the last one which ended only a few thousand years ago. This did not fit with the La Place theory, according to which our last glacial period was the "beginning of the end" of a cooling earth about to conclude the days of its living inhabitants by freezing them to death.

At once the theory of La Place began to be questioned by Professor Chamberlin. The research which he had started to find a cause for the last glacial period was extended to discover the answer to a greater question, the origin of the earth itself. With the assistance of his scientific associates, Moulton and others in the University of Chicago, he began to study the facts that astronomers had learned about the solar system to see if the theory of La Place had other weaknesses. Many facts were discovered which this theory failed to explain. The original sphere of fiery gas, he found, must have been less than one-millionth as dense as our atmosphere. Progress in the knowledge of gases since the time of La Place showed that the expansive power of such a thin cloud of gas would have been greater than the power of its own gravity attraction to hold it together; therefore such a

sphere of gas could not have contracted into a solar system. Its own expansive power would have driven it out into the universe and dissipated it.

Further study showed that if the sphere of gas had contracted in the manner that La Place thought, the speed of rotation of the sun would necessarily have become many times greater than it is. The mass of the sun is 700 times that of all the planets together; yet its energy of rotation—which on the La Place theory should be 700 times the energy of the rest of the solar system—is less than 2 per cent of the total whirling energy of the whole system. If one had a great lever by the use of which he could stop the sun from rotating, he would have to exert only one-fiftieth of the energy needed to stop the planet Jupiter from revolving about the sun.

For these and other equally strong reasons it became evident that the La Place theory could no longer be used to explain the origin of the earth; so the idea of a molten globe with a thin solid crust had to be abandoned. Modern observations of the earth's behavior in transmitting earthquake waves show us that the interior of the earth, instead of being a liquid molten mass, is solid and as heavy and rigid as the hardest steel. Yet the La Place theory had become so firmly fixed in the

thoughts of men that it still persists, and the ideas built upon the discarded theory are still taught.

The old theory having been found incapable of explaining the facts, the problem was to construct a satisfactory new theory. Professor Chamberlin and his associates proceeded to do this. Out of their studies they arrived at the present generally accepted theory of the origin of the earth. They found that the origin of the solar system could be explained according to all the scientific facts and laws we now know, if we assume that the sun were approached by some other large heavenly body close enough to cause the sun to throw out, as great streamers, about one seven-hundredth part of its mass. These streamers would quickly take on circular orbits of travel about the sun, and any molten lumps would soon cool to a solid condition. Because of the attraction of gravity they would then gradually accumulate about the larger masses and thus grow to planets of the sizes and positions we now find in the sun's family. The last remnants of the original swarm still fall upon the earth—our familiar "shooting stars" or meteors.

These little planets, or planetesimals of cold solid matter that gradually accumulated to make the larger planets, give the name Planetesimal

Hypothesis to Chamberlin's theory of the origin of the earth.

The building up of the earth from a small mass to its present size by the accumulation of various sized planetisimals probably took many millions of years. In its earlier stages when the mass was small, the attraction of gravity was much less than it is now. Lighter materials, such as water vapor and gases, could not be permanently held but would fly off into space. The earth once was like the moon and had no atmosphere. As it grew larger and the force of gravity increased in proportion, water vapor and a thin atmosphere could be retained. Conditions must then have been much like those we see on Mars today with our telescopes. As the size increased, a thicker atmosphere could be held, and water vapor could condense and be retained as water. As more water vapor condensed, there would begin the accumulation of seas in the depressions, rainfall and streams could develop, and the familiar processes of erosion and deposition could begin the work they have continued ever since.

As the size of the earth increased, the force of gravity became greater. This compelled the planetesimals to pack themselves closer together, and they began to heat up from the friction created. As this heat accumulated, it became

sufficient to melt the lighter and more easily melted materials. This molten rock was then squeezed out to the surface. As the size kept on increasing, the material squeezed out would be buried beneath in-falling planetesimals and would again be melted and squeezed to the new surface. In this way, it is believed, the earth has reached its present condition, with a core as heavy as steel surrounded by a crust of rock that weighs about one-third as much per cubic foot.

The nature of the core and of all but the outer few thousand feet of the crust can be known only from studies we can pursue at the surface. We can weigh the earth very accurately. We can measure its rigidity quite satisfactorily at various depths by its reaction to tides and earthquake waves. We can make fair guesses at its internal temperature. From these basic facts, or near-facts, most scientists now believe the earth's core to be almost wholly composed of nickel-iron alloy like the iron meteors that we see. About this core is believed to be a thick layer of the heaviest kinds of rocks, which contain much iron along with their silica, lime, and other of the less heavy elements. The continents are believed to be more largely composed of rocks that have still less iron, rocks chiefly of the granite type and sediments derived from them. These three zones of rocks

are progressively lighter. A cubic foot of the core of nickel-iron weighs about 7.5 times as much as a cubic foot of water. The heavy rock zone weighs 3 to 3.5 times as much as water, and the outer shell weighs a little over 2.5 times as much as water. The weight of the whole earth is about 5.6 times as great as the weight of a globe of water of the same size.

According to the planetesimal hypothesis of Chamberlin, the earth had both a father and a mother. The father was an unknown star that came so close that its attraction drew away from the sun the mass of material that later gathered together to make her family of planets. She has been deserted by the father of her brood, who has gone on his unknown course through the heavens. She has watched her children grow to mature size and has all this time warmed them and kept them obedient to her will. She has watched one of her daughters—our earth—bring forth a multitudinous brood of living things, which may consider themselves to be grand-children of the sun.

Details of this early history are only in small part worked out. The story is far from complete. Fragmentary as it is, the grand drama needs the abilities of a super-Homer to portray its majestic splendor and its limitless wealth of time.

CHAPTER IV

THE AGE OF THE EARTH

IN STUDYING the history revealed to us in the rocks, it has been of great interest to many men of science to consider how far back the record goes. Geologists, physicists, and chemists have all been interested in the problem and have tried in various ways to find some measure of the number of years it has taken to build up this record. After Hutton, the Scotch farmer, recognized the significance of erosion and deposition and stated that he saw "no vestige of a beginning, no prospect of an end," the immensity of the time it had taken to complete the many cycles of erosion and deposition began to be apparent. Geologists had to be content at first with the indefinite conclusion that there had been *time enough*, that the natural processes which produced the record had taken their own time to accomplish their work. In the middle of the last century geologists were inclined to believe that it must have required at least a hundred million years to produce the results they found.

In the final third of the last century students of

physics began to pay attention to the problem of the age of the earth. On the assumption that the contracting earth formerly rotated on its axis so fast that the moon was left behind in the same way the La Place theory pictured the planets to have been formed from the sun, G. H. Darwin computed that the time which had elapsed since that event amounted to fifty-seven million years. Lord Kelvin, assuming an initial temperature and an average rate of cooling, which, of course, he could not know definitely, computed the time it would take an earth of molten material to cool to its present temperature. He estimated that from twenty to forty million years ago the surface of the earth must have been a molten sea of rock. These estimates were not welcomed by the geologists, for they could not see how such a limited time was sufficient to complete the events they found recorded in the rocks.

A third method of estimating the age of the earth became possible as more definite knowledge of the amount of salt in the sea and in the great rivers of the world became available. When fairly accurate estimates of these quantities could be made, it was a matter of simple arithmetic to divide the annual tonnage of salt which the rivers carried to the sea into the tons already there and find how long it had taken to accumulate the total. Joly

found that this method permitted an estimate of eighty to ninety million years as the time required for the sea to accumulate its present amount of salt. This was more satisfactory to the geologists, but the time still seemed somewhat short.

The geologists studied the thicknesses of the various sandstone, shale, and limestone beds and tried to figure how long it might have taken to form these deposits. The difficulty with this method was the lack of definite knowledge of just how long it took to deposit a foot of these rocks. It is true that estimates could be made of the amount of material carried into the sea by the great rivers. The Mississippi was found to carry sufficient sediment to lower its basin an average of one foot in three or four thousand years. From this the amount of material delivered to the sea and deposited by it in the shallower areas off the coast could be estimated. But this gave only a rough method of computing the average time necessary for a foot of sediment to be deposited. Furthermore, it related only to present conditions. What the rate had been in past geologic eras, when the continental area had in general been smaller and of lesser elevation above sea level, the geologist could not tell with desirable accuracy. He could not dispute the physicists with definite and conclusive figures, but he still believed that the time they allowed was not sufficient.

After the discovery in 1896 that certain minerals possessed radioactive properties, the physicists found that the behavior of these minerals could be used in computing their age. This method furnishes us with the best *geologic clock* that we possess to measure the duration of the time it has taken to build up the geologic record. At first the results were rather embarrassing to the geologist because they indicated a length of time far greater than he had dared estimate before. The physicist had been telling him that the age of the earth was shorter than his observations seemed to indicate. Now the physicist by this new method gave him almost too long a time.

In order to understand this method of measuring time, it will be necessary to take a brief side trip from our geologic path into the realms of physics and chemistry. In all the years preceding the last century little had been learned about the chemical constituents of the familiar substances about us. The philosophers of ancient Greece had believed that matter was composed of ultimate particles too small to see. They believed that if you subdivided any substance you would eventually reach a small particle that could not be divided further. This "indivisible" or "uncuttable" particle they called the "atom," the Greek term for "indivisible."

About a century ago, when chemistry as a science was in its infancy, chemists were finding that most material things could be separated into substances which could not be further simplified. These final substances they called elements. They proceeded to investigate all manner of materials and discover new elements. The air was found to be a mixture of oxygen and nitrogen. Among minerals they found quartz to be a chemical compound of the metal silicon and the gas oxygen. Iron ore they found to be a compound of oxygen and the metal iron. Water was found to be composed of two gases, oxygen and hydrogen.

The hunt for new chemical elements has been a most exciting scientific adventure. Not all of them have yet been isolated, but those we know fall into a system so definite and perfect that we feel sure that there are only 92. The chemists came to the conclusion that there must be invisibly small, bullet-like ultimate particles of each element, just as the ancient Greek philosophers had supposed. They therefore used the name atom for these ultimate particles. Later study near the end of the last century developed the theory that the atom is not a simple bullet-like mass but is really a system of revolving particles, somewhat similar to our solar system in arrangement and behavior. Corresponding to the sun at the center

of the solar system, the center of the atom was found to be made of two or more tiny particles of positive electricity called "protons." Corresponding to the planets revolving about the sun are the electrons, which are tiny charges of negative electricity, each whirling around the center of the atom in the same way that the earth revolves about the sun.

When certain minerals were found to give off rays that would penetrate opaque substances in the same manner as X-rays, the question arose as to what these rays were. It was soon discovered that there are three kinds, which are distinguishable by their ability to penetrate different thicknesses of opaque material. These were named "alpha," "beta," and "gamma" from the first three letters of the Greek alphabet. The alpha rays were found to be atoms of helium, each composed of four protons and two electrons; the beta rays to be electrons; and the gamma rays to be electromagnetic pulses like X-rays.

Though these rays are not visible to the naked eye, it was found that if alpha rays are allowed to strike a surface of phosphorescent zinc sulphide they cause visible star-like points of light. These star-like scintillations can be seen on the luminous hands of a watch if you will look at it with a strong magnifying glass. By this method and others

more exact it was found possible to count the number of atoms of helium given off by a radioactive element. The number is always the same for the same period of time and the same weight of radioactive substance. The constant rate of emission gives us one of the factors necessary for our "geologic clock."

The only other factor needed to complete this clock, with its remarkably constant rate, was some means of telling how long the clock has been running—how many "ticks" it has made since it was started. Fortunately this was soon discovered. The most common radioactive mineral is uraninite, a chemical compound of uranium and oxygen. The atom of uranium is a miniature solar system with 238 protons in its central sun and a flock of electron planets circling about it with the speed of light. At regular intervals something happens to this miniature solar system, and it loses four protons with the appropriate number of electron planets required to make an alpha particle—an atom of helium. After this atom of helium has been lost, the remainder no longer has the properties of uranium but has become an atom of a different substance. When it has lost three atoms of helium, it becomes an atom of radium and has 226 protons left. This atom of radium continues to give off helium atoms. When the original ura-

nium atom has lost eight helium atoms with their thirty-two protons, it has two hundred and six protons left and has become lead—an element entirely different from uranium or radium. This lead no longer loses helium atoms but continues to exist as lead from that time on.

This completes the second factor in our geologic clock. If we can find how many atoms of lead have been produced in this way we can tell, from the known rate of change, the total time during which the uranium has been disintegrating. Mathematical calculations, which it is not necessary to discuss, give us the number of years since the original uraninite was solidified, along with the other minerals, in the rock where it is found.

In this way during the last fifteen years the age of rocks of various geologic periods shown in Table 1 (page 55) has been determined. The work has been done with an accuracy which has never before been attained and which is satisfactory to both the physicist and the geologist.

In the many repeated cycles of uplift and depression, of erosion, deposition, and alteration (metamorphism) the record which has been preserved in rocks that are more than a half-billion years old has been rendered so difficult to read that about all the geologist could say of such rocks was that they were very old. Which rocks

were the oldest he could not tell until the uranium-lead geologic clock was discovered. This clock now enables us to put time labels on the ancient rocks. One of the oldest thus far found is in the Black Hills of South Dakota. Its age is nearly a billion and a half years.

In discussing the age of the earth we need to define what we mean by the term. We could start from the beginning and take the period since the planetesimals were first thrown off from the sun, or we could take the opposite course and measure back from the present to the time when the oldest rock was formed. The discussion of the age of the earth in this chapter includes only the time elapsed since the oldest known rocks now found at the earth's surface solidified from their previous condition, whatever that may have been. It includes the time in which the earth has had its present size and shape and during which its general physical condition has not been greatly different from that which we now observe. This age is probably not less than sixteen hundred million years, a period of time far too long to be measured by minds that often think hours are unbearably long intervals.

CHAPTER V

THE RECORD OF LIVING THINGS

IN THE story of the discoveries of the Scotch farmer, Hutton, it was indicated briefly that successive beds of sand, lime mud, and clay had been deposited over large areas. In the story of the Wisconsin mill pond mention was made that some of the layers were found to contain the remains of leaves which had settled in the pond with the mud. During the deposition of the sands and clays and lime mud, which were hardened into rock to make the cliffs that Hutton examined, there were likewise deposited the remains of various living things—shells, skeletons of animals, pieces of vegetation, all sorts of things that might leave their imprints when these unconsolidated materials were later hardened into rocks. Such remains of living things have been of great value in helping us to unravel the story of the past from the study of these various rock beds.

As men studied these remains more and more, they noted that individual beds were characterized by certain types of animal and vegetable forms. Other beds above or below were charac-

terized by different types. About one hundred years ago it began to be recognized that these remains, which are called fossils, are so definitely characteristic of the beds in which they occur that they make a most excellent means of identifying particular beds wherever they are found. When a certain group of fossils was found in a bed in eastern New York and the same group of fossils in the same kind of bed could be traced clear across the country from quarry to quarry, from hillside to hillside, it became apparent that this particular bed must have been deposited in a sea of that extent and that conditions in this sea were favorable to the existence of this kind of shells.

As lower, and therefore older, beds were examined it was found that in a general way the living forms were simpler as the age of the beds increased. As the overlying beds were examined, it was found that the forms of life usually became more complex, until in the more recent of these beds remains of higher animals and of man were found. As a result of these studies it was found that the whole series of beds laid down in the past could be divided into groups characterized by the forms of life which they contained. On the basis of this life history of the past the geologic eras have been named.

The oldest rocks found are those of the Protero-

zoic Era. They contain either no evidence of life or evidence that is very hazy and indefinite. Such fossils as exist are chiefly of microscopic simple forms, single-celled animals and plants like those we find in the waters of the sea and lakes today. Few of these earliest forms of life possessed hard parts that could be readily preserved.

After long ages, toward the end of the Proterozoic Era, and at the beginning of the next era, some living forms began to protect themselves with a hard shell or "exterior skeleton." Still later on larger and more complex organisms appeared, various kinds of shell fish and other small forms of life, much like those we find along our sea coasts and lake beaches today. About the middle of this era the first fishes began to appear, the earliest animals to possess a backbone. Toward the close of the era some of these developed the capacity to breathe and so to live on land as well as in water and thus became the first of what we call amphibians. This period of life development is given the name of the Paleozoic Era, which means "early life era."

The third great era was characterized by the development of enormous land animals and has been called the "Age of Reptiles." This era has been given the name of Mesozoic, meaning "middle forms of life." The great dinosaurs,

which reached their highest development at this time, were among the largest land animals ever to inhabit the face of the globe. Most of them were animals that laid eggs, just as fish and turtles and alligators do at present. Most of them left their young to hatch out and care for themselves unaided from the day they were born. Their lives were easy, and they prospered and developed many different forms. Some were plant-eating and some were flesh-eating. Some of them found it easiest to get their food by swimming in the seas of those days and gradually developed the capacity to live in water. These reversed the experiences of their ancestors who had developed from fish that got tired of living in the water and developed lungs so that they could live on the land.

Toward the end of the Mesozoic Era a higher type of animal appeared which brought forth its young alive and cared for them and nursed them through a period of infancy. This great group of animals rules the earth today. They are known as mammals, a term which includes all animals which nurse their young. Just as some of the reptiles of the Mesozoic Era found an easier livelihood by returning to the sea to live, so in this later era some of the mammals found it desirable to live in the water. Thus were developed the whales, dolphins,

and porpoises, inhabitants of our seas today, which bear living young and nurse them. This latest era of geologic time, which followed the Age of Reptiles, or Mesozoic Era, is given the name of the Age of Mammals, or Cenozoic Era.

These great eras of the geologic past and their equivalent in millions of years are shown in Table 1.

You will notice in Table 1 that the grand divisions of geologic time are known as Eras. These are divided into Periods which are in turn subdivided into Epochs. Epochs are further subdivided into Ages, but that is getting too far into technical detail. The division of the geologic past into epochs and ages has been by no means fully worked out. Much remains to be done before our knowledge is complete. Further study will lead geologists to amend Table 1 as new facts are discovered. Geology, like all other sciences, is a progressing, developing state of knowledge, no field of which will be completely known for long ages.

Each of the divisions of geologic time is, on a much grander scale, similar to the "epoch" of the deposits in the Wisconsin mill pond. As that began with the building of a dam which changed the conditions from those of an eroding valley to those of quiet water where the stream deposited its sediment, so each of them began with some

Geologic Time Scale

This table is based on one prepared by Professor Charles Schuchert for Bulletin 80 of the National Research Council published in 1931.

Eras	Periods	Epochs	Duration in Millions of Years	Time Since Beginning of Each Epoch in Millions of Years
Cenozoic (Recent Life)	Quaternary	Recent Pleistocene	2	2
	Tertiary	Pliocene	15	17
		Miocene	20	37
		Oligocene	10	47
		Eocene	13	60
Mesozoic (Middle Life)	Cretaceous	Upper Cretaceous	41	101
		Lower Cretaceous	21	122
	Jurassic		31	153
	Triassic		27	180
Paleozoic (Early Life)	Carboniferous	Permian	36	216
		Pennsylvanian	47	263
		Mississippian	36	299
	Devonian		44	343
	Silurian		26	369
	Ordovician		42	411
	Canadian		23	434
	Ozarkian		27	461
	Cambrian		79	540
Proterozoic (Earliest Life)			?	1600?

event that changed the previous conditions. Nothing so insignificant as the building of a dam marked these eras, but some vaster thing, such as the slow submergence by the sea of half a continent, or the elevation of a great chain of mountains. The most important changes marked the close of one era and the beginning of another. Less important changes of this kind marked the ends of periods, epochs, and ages.

The close of the Paleozoic Era (early life) was marked by a great earth movement, estimated to have occurred about one hundred and eighty million years ago. This movement compressed and tilted the rocks that now make the Appalachian Mountains and raised them and the whole eastern part of the United States above sea level. How long a time this took we do not know, but we do know enough to feel quite sure that the process was too slow to be noticed by any casual observer, had there been one present. At the rate of one inch per year the highest peak in the Appalachians could have been elevated from sea level in seventy-five thousand years. In some parts of our country there are probably vertical movements of the earth's surface now going on at this rate, or even more rapid rates, which are entirely unnoticed by the people living there. Yet it is probable that the building of the Appalachian Mountains

took place at a slower rate and occupied a much longer time.

The close of the Paleozoic and the beginning of the Mesozoic Eras, then, were marked by the mountain-building uplift that resulted in our Appalachian ranges. The end of the Mesozoic and the beginning of the Cenozoic Eras were similarly marked by the elevation and folding of the Rocky Mountains. According to Table 1, this was approximately sixty million years ago. Our Rocky Mountains apparently are mere youths, only a third as old as their feeble grandfathers in the east.

The Sierra and Coast ranges along our west coast are mere infants, only about a third as old as the Rockies or perhaps even less.

The events marking the ends of geologic eras have been mentioned because of their bearing on the story of living things shown by the rocks. The elevation of vast areas above sea level, or depression below it, changed living conditions very greatly. Ocean currents were deflected into new courses. Where there had been warm water there was perhaps now cold, and vice versa. Organisms that had thrived before died under the changed conditions or underwent modifications that adapted them to the change. New types of organisms immigrated and ate up or drove out the

old. So there were vast changes in the kinds of remains of life that were deposited in the sediments of the sea and shore. If you will consult a text book of geology and will turn first to the illustrations of the fossils found in Paleozoic rocks and then to those found in Mesozoic, you will find that even without knowing anything about their long specific names or attempting to qualify yourself as a paleontologist (one who studies fossils) you can see quite notable differences.

If you will refer to Table 1, you will note that there are a number of epochs in each era and that the average length of each of these epochs for the last 299 million years is more than twenty million years. In one of the epochs there was time for many changes in living forms to take place. When we consider the wide variety of kinds and sizes of dogs and cattle produced in a relatively few centuries by careful breeding, and then try to think of what might happen in only one geologic epoch of an average length of twenty million years, and then, if imagination is not already stretched to the breaking point, try to still further multiply this by fifty to get the record of a billion years, it is not difficult to see how living things in their struggles for existence have had ample time to develop from the simplest forms of one-celled beings to that exceedingly complex, little under-

stood, but "inordinately proud" being that calls himself man.

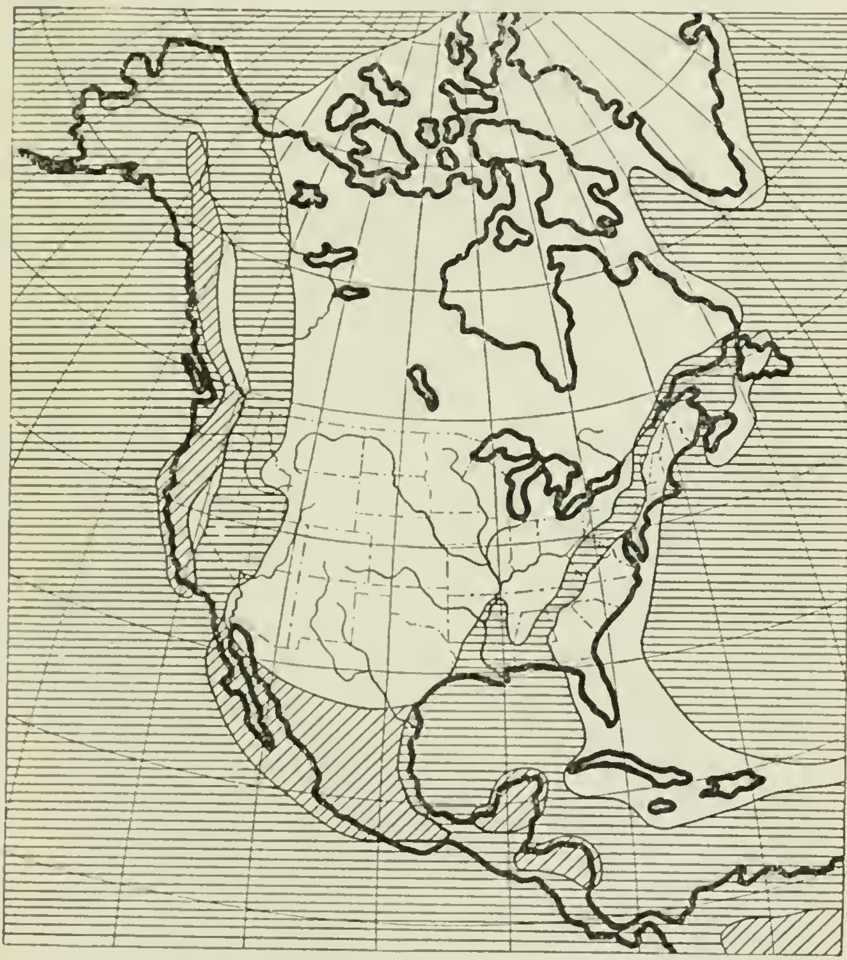

FIG. 4. The part of North America that was probably land about 540 million years ago, in the Lower Cambrian Period, is shown in white. The area covered by sediments deposited in seas of that period is shown by the horizontal lines. The inclined lines show areas possibly covered by the sea, but not definitely known to be. After Bayley Willis.

One of the great steps toward dominating the earth was the development of life forms that were able to live upon and occupy the land. All the earlier forms were probably water-dwellers. In earliest times the land was barren of plants and animals. No living thing grew or crawled beyond the shore. If by accident it was left out of water, it promptly died. There is evidence that this condition prevailed in all the history of the earth up to a half-billion years ago. The landscape then consisted of bare rocks and sand and mud, deposits lying stark and naked as the rains and rivers of those ages left them. The landscape must have looked like a desert; yet in most of the world the rainfall was about as abundant as it is today.

Remains found in the rocks indicate that about five hundred million years ago, in the Cambrian Period, some few of the plants—which previously had all been sea plants—had found a way to live on land. They were the highest plant forms of their time, even though they were only algae and the simplest of mosses. They first found a precarious living along the rocks of the sea coast. Later on, after a hundred million years of progressive adjustment to their "new" surroundings, they began to look somewhat like some of the plants we see today.

About three hundred million years ago plants

Fig. 5. A landscape showing the vegetation of the Carboniferous Period about 260 million years ago. This dense growth of fernlike forms grew as tall as many modern trees. The remains of this vegetation attained thicknesses of many feet and were buried and compressed and altered into the coal-beds which we mine today. Photograph published by permission of the American Museum of Natural History, New York.

had developed swamp-living forms of moderate size, and in the Carboniferous Period, two hundred and fifty million years ago, great tree ferns and similar forms grew to a height of eighty feet. These forms and their associates accumulated in their swamp homes to considerable thickness, so that today they make one of our most valuable mineral resources. They used the sunlight of those days to transform water and carbon dioxide from the air into woody cellulose which was altered into the coal which we now use to drive our trains, run our factories, and light our homes. In fact, we might truly say that our present civilization is largely based on the sunshine that fell on the earth two hundred and fifty million years ago.

Plants continued to develop newer and better and more complex forms. About two hundred million years ago, in the Permian Epoch, the first cone-bearing trees appeared. About one hundred million years ago, in the Cretaceous Period, seed-bearing plants developed in abundance. Most plants up to that time had been spore-bearers like our ferns today. When the first seed-bearers appeared, they were so much better fitted to land conditions that they quickly became the dominant type of vegetation, a position which they hold today. They include all our grasses and grains and our fruit and nut-bearing trees. The spore-

bearers have literally been relegated to the shade by the seed-bearers.

It is a most interesting thing to study this development of plant life as portrayed in the rocks. We see the evident striving for adjustment to prevailing living conditions. We see the plants making experiments, as it were, trying to see whether this kind of change or that would permit them to conquer and occupy territory from which they had hitherto been debarred. We find that some experiments were huge successes, the plants quickly multiplying to cover large areas. If the experiment was not a success or developed a form adapted only to a temporary set of living conditions, the plants soon died out and disappeared from the earth. Thus all through the record in the rocks we can read of gradual improvement and progress toward a perfection still to be attained. It is as though the Creator had implanted a yearning for perfection in the first living things and we were privileged to sit and watch this progress from the crudest beginnings to the present through the whole long procession of a billion years.

The development of animal life has a similar history. The earliest animal forms are concealed in the hazy and indistinct records of the very ancient—rocks. At first all animals, like plants,

were sea-dwellers and were long in developing hard parts, such as shells or bones, that would not be easily destroyed and "sunk without trace."

In rocks of the Cambrian Period, which began more than five hundred million years ago, we find our first well-preserved evidence of an abundance of animal life. In older rocks, fossils are few in numbers not because living beings were scarce but because few of them had discovered how to utilize the lime in the water to build themselves stony protective armor. When this discovery was made, the rocks at once began to preserve the remains of an abundance of different forms of life, many of them quite complex in their organization. Those who have studied the long, slow evolution of living forms from the lowest to the highest have estimated that from sixty to ninety per cent of this evolution occurred before the Cambrian Period began. We find in these Cambrian rocks the remains of many hundreds of species of animals. Some are shellfish somewhat like our modern clams and oysters, others are similar to modern snails in having coiled shells, and still others are like corals in structure.

The largest and most complex animal of those times was a trilobite about twenty inches long. It possessed most of the organs found in the animals of the present day. It had a well-developed

digestive tract, feeling organs, a co-ordinated muscular system, an external protective shell like the crab and lobster of today, eyes, and a well-developed nervous system with a central brain of minute size. It had all our five senses with the possible exception of hearing and smelling.

The next step in the evolution of animal life, the conquest of the land, required what to us seems a long period of time—perhaps 150 million years. It could not be completed until plants had become land-dwellers. The earliest land animals found in the rocks are insects, spiders, and scorpions, which appeared about three hundred and sixty million years ago in the Silurian Period, and reached a high development in the Mesozoic Era, which covered the period of time from 180 million to 100 million years ago.

The first vertebrate skeleton was owned by an ancestral fish that lived perhaps four hundred million years ago in the Ordovician Period. He had found that he needed something to keep his head from being driven back into his body as he swam about in search of his prey, and so he grew a bony skeleton and discovered that life was easier. His predecessors all had "external skeletons," or shells, that were good armor against their enemies but were cumbersome and cut down the speed with which they could navigate and catch the other

Fig. 6. A landscape and some of the leading inhabitants of the earth in the Mesozoic Era, about 150 million years ago. These dinosaurs left their remains near Medicine Bow, Wyoming. This species is known as Brontosaurus, the Thunder Lizard. There were many other species of dinosaurs, both large and small. Photograph copyrighted by the American Museum of Natural History, New York. Published by permission.

organisms upon which they lived. This development of a backbone was an improvement of such great usefulness that all higher types of animals since that time have an internal jointed skeleton, the main feature of which is a flexible, jointed backbone. Nothing has been invented by nature thus far that is better for its purpose than this great device. It has been the prime factor that has enabled animals to attain to great size.

Since the first animal with a vertebrate skeleton appeared four hundred million years ago, there has been progress in size, until today we now have the largest animal that ever lived, the great blue whale, which is known to have attained a length of 106 feet. Progress was not rapid. One hundred million years had to pass after the invention of the backbone before animals ten feet long developed. It was not until the vertebrates took to living on the land that development to great size occurred. In the Age of Reptiles—the Mesozoic Era—when the dinosaurs and their kin were lords of creation, they so "quickly" added to their size that not more than thirty or forty million years of this era elapsed before they had attained to maximum lengths of seventy feet. This experiment of increasing the bulk of flesh inside one skin—or, to look at it from the inside out, the bulk of flesh surrounding a single backbone—was successful for

about seventy-five million years, and the great animals of the period prospered for a time lasting from one hundred and fifty million years ago to seventy-five million years ago.

The development of these animals to greater size was not accompanied by corresponding brain development. The largest brain of those days was less than a quarter the size of yours or mine.

The following verses (written by my friend and colleague, Prof. A. E. Seaman) humorously picture the dinosaurs' lack of brain and their downfall.

THE DINOSAURS

By Professor A. E. Seaman

The dinosaurs were mighty beasts,
Renowned for bulk and strength;
Their necks were measured by the yard,
Their tails had greater length;
Their heads were small, and
All in all, they were not very wise,
But what they lacked in intellect
They made up for in size.

* * *

But while their head held one small brain,
And none too finely wrought,
Their sacrum held a larger one,
And was their seat of thought.
There were ganglia knots along their spine,
Scattered from stem to stern;
While these were only scatter brains,
It gave them chance to learn.

Such brains were fine for retrospect—
For looking o'er the past—
But since their forethought was so slight,
The poor beasts could not last;
They failed to see the "rocks ahead,"
That round them they might steer,
And so they met the fate of all
Whose brains are in the rear.

In the meantime nature was making a different kind of experiment. The great reptiles did not have any marked maternal instincts. Most of them continued the practice which characterized the poor fish and lower animals that had been left behind in the race. They laid eggs and left their young to hatch out and care for themselves. About one hundred and fifty million years ago there appeared some small animals that hatched their eggs inside their bodies and produced living young, which they nursed and cared for through a period of helpless infancy. From this habit of nursing their young they have been given the name of mammals. With them the great quality of mother-love first began to be an important factor in the life of the earth. Through at least eight hundred and fifty million long years of the billion-year story living beings got along with little or none of the mother-love that is so powerful an influence in the lives of all of the higher animals today.

Mammals also gave up an old practice followed by all other living things, that of being cold-blooded. They found that to elevate the blood temperature gave them advantages over their cold-blooded associates. Warm blood and the habit of nursing their young were the most important new elements in life that distinguished the mammals. They had the same organs, muscles, nervous system, and brain as their cold-blooded, egg-laying neighbors, but they had in the two new improvements qualities that were to make them, after a hundred millions of years had elapsed, the dominant type of animals on the face of the globe. For the last sixty million years they have prospered more extensively than any other kind of animal life.

The story told by the rocks relates that, after the success of the mammals as a dominant type of animal life, nature began another major experiment, the development of a larger brain. The invention of the shell or external skeleton she had bettered by inventing the jointed backbone. This had made possible the reptilian conquest of the land. The reptilian experiment she had largely discarded after the successful development of mammals.

Before this last experiment the largest brain in the world was probably no larger than one-quarter

the size of the average human brain, was much less finely organized, and was much less than a quarter as capable.

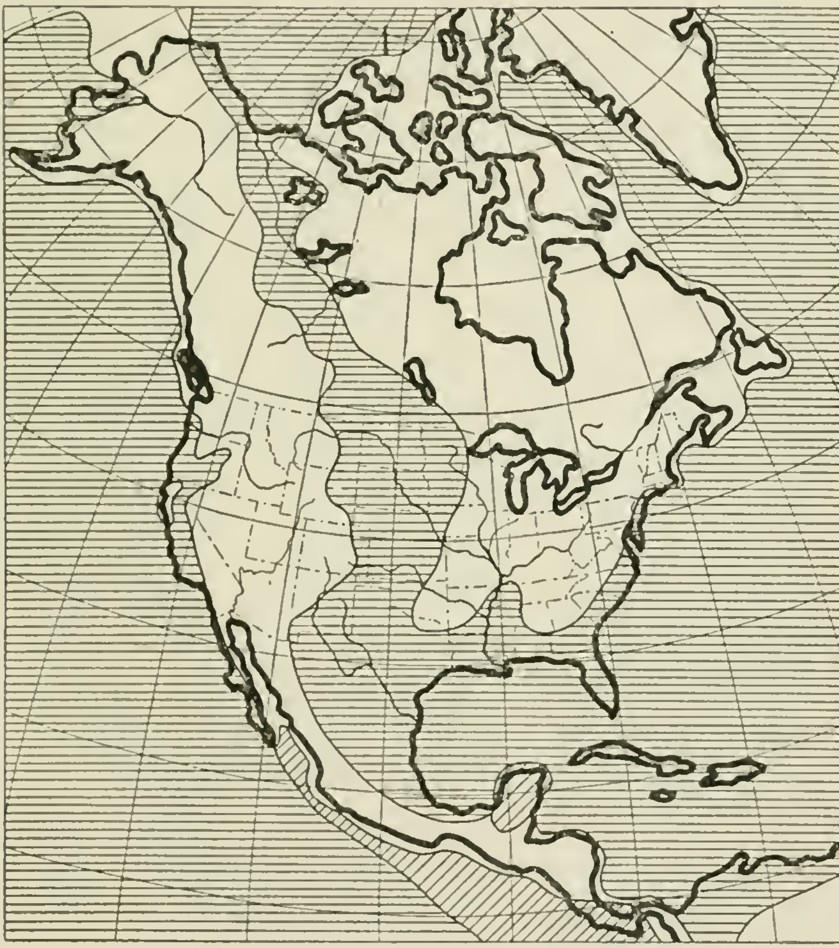

FIG. 7. The part of North America that was probably land about 100 million years ago, in the Upper Cretaceous Epoch, is shown in white. The area covered by sediments deposited in seas of that epoch is shown by the horizontal lines. The inclined lines show areas possibly covered by the sea, but not definitely known to have been. After Bayley Willis.

In early Tertiary time, during the first period of the ascendancy of mammals, there was one kind that began to live in trees. In all animals living on the ground the sense of smell had been highly developed and was most useful. In the tree-dwellers this sense lost its importance, and the sense of sight became of greater value. Consequently, sight was developed more highly as the ages rolled on. The conformation of the skull changed so that the two eyes could look straight ahead and both eyes could see the same object. This change was associated with a corresponding development of the parts of the brain which related to vision. This made possible the kind of vision that enables its possessor to estimate distances. If a ground-dweller does not estimate distance correctly when leaping for his prey, he only loses a meal. If a tree-dweller misjudges the distance of a branch he leaps for, he is in a far worse plight—he is quite likely to lose his life. The quickness of movement of these tree-dwellers undoubtedly made increased brain capacity a great asset to them, and so those with better brains prospered and propagated their kind.

Tree-dwelling developed the grasping capacity of the extremities and the capacity to balance and walk on the hind legs. All these things made brains more of an asset. The grasping capacity of

the fore limbs permitted the use of clubs, which began to come into style as weapons.

When the tail-less, hind-foot-walking, man-like apes—anthropoids—appeared in the Oligocene Epoch, about forty million years ago as the story of the rocks reveals, brain capacity increased. Some of the best of these apes had brains one-third the size of man's.

The oldest erect-walking man, whose skull was found in the rocks of Java, had a brain sixty per cent as large as ours. The rocks in which his remains were found date back possibly to a period from two to five million years ago—the late Pliocene Epoch—but the number of years is getting so short that our measuring scale is very inaccurate. Whether this time is two million or ten million we do not know. Whether this Java man is really to be classed as a low-type man or a high type of anthropoid is not a matter on which all scientists agree. What is more important is that his brain was about sixty per cent as large as that of modern man.

After the time of the Java man came the great change in climate which produced the Glacial Epoch discussed in Chapter VII, when great continental ice sheets spread over the land from the north. South of the margin of the ice the climate became colder. Man had to develop to meet this

emergency, or perish. He already had the capacity to use clubs, bones, and stones as weapons. At this time he probably learned to use fire, to live in caves, and to build himself shelters in which he could find relief from the cold. The remains found in the rocks tell this story in a sketchy fashion which as yet is far from satisfactory, but they do inform us positively of the facts given above and also of the size of his brain cavity, which was ninety per cent as large as ours.

This brings us to the scientific domain of the anthropologist, where we may leave the development of the human brain and its tremendous significance.

To see the success of this latest experiment of nature—the development of the brain—you need only look about you, and, with the background of the story of a billion years, consider how completely man dominates the world in which he lives, how he has mastered fire, water, earth, and air, how he has tamed the lightning of the heavens and made it his servant, how he has learned to bring wealth from a depth far below the surface and use it for his convenience, how he has multiplied in numbers and learned to control all other forms of life and the great forces of nature so that they minister to his welfare.

I once heard a friend facetiously remark that it

was too bad that Moses was not a better geologist. And continuing, he said, "If he had been, instead of writing a story of the *fall of man* and his decline from previous perfection he could have written a much more inspiring and hopeful tale of the *rise of man* from lowly beginnings in the remote past, with the unlimited possibilities of the future before him." It is truly a most satisfying experience in reverence for the Creator of all things to read in the record not made by human hands this great story of the past and then to turn and look into the future which is developing so rapidly before our eyes.

CHAPTER VI

CLIMATES OF THE PAST

As we look over the universe with our astronomical friends we find a wide variety of conditions. We find all degrees of temperature, from the intense heat of stars far hotter than our sun to the bitter cold of space, 460° below zero Fahrenheit, a total difference of many thousands of degrees. We find one of the planets with a thick, always cloudy atmosphere that never lets the direct rays of the sun through to the planet's surface. We find others with no water or clouds and little or no atmosphere.

Study of the heavenly bodies forces us to conclude that the climatic conditions under which we live on this earth of ours are not duplicated on any other member of our solar system. The plants and animals with which we share the earth would all die if the temperature of the earth were to increase to the boiling point or to decrease permanently below the freezing point. This narrow range of temperature—180°F.—must have been maintained through all the many hundreds of millions of years that life has existed here. Life, as

we know it, can exist only in a narrow range of conditions. It must have oxygen; yet it cannot exist in an atmosphere of pure oxygen or in one in which the oxygen is reduced to a quarter of that in our atmosphere. It must have a proper amount of carbon dioxide. It must have water. All these favorable conditions—sufficient water, proper composition of the atmosphere, and proper temperature—must have existed on the earth as long as life has been present. Whatever variations the climates of past geologic ages may have undergone, we know that the greater part of the earth has for a billion years possessed a climate within the limits of conditions favorable to the continued existence of living beings. Within this range, however, the story written in the rocks tells of many changes in climate. There were times when the poles possessed a temperate or subtropical climate, and other times when great continental ice sheets existed almost at the equator.

The climate of a locality is its average weather. It is described in terms of the temperature, moisture, and wind. We speak of hot or cold climates, of moist or desert climates, and, less often, of windy climate. Thus the heat that we receive from the sun and its distribution over the earth are the most important factors in climate.

In our homes heat is distributed throughout the

house from some heating plant, a stove or furnace, by hot air, by steam (or water vapor), or by hot water. The earth uses all three of these methods of distributing the heat it receives from the sun. The oceans and the air are warmed in the equatorial regions where the greatest amount of heat is received from the sun. The warmer air and water are lighter than the colder air and water toward the poles, and thus are set up great ocean currents, such as the Gulf Stream in the Atlantic and the Japan Current in the Pacific, and also great air movements which we know by such names as prevailing westerlies, trade winds, and monsoons. These water and air currents distribute their heat over the earth. They are its "hot water" and "hot air" heating systems.

The air currents also transport water vapor from oceans and other bodies of water and drop it as rain. This is the vapor-heating system that helps to distribute the sun's heat over the earth. When water is evaporated, it absorbs great quantities of heat. When the vapor is again condensed to water, the heat absorbed in evaporation is given off. The amount of heat energy which is given off at the place where vapor is condensed to fall as rain is surprisingly great.

In the vicinity of Chicago the annual rainfall amounts to about 30 inches. On an area 100 feet

square, about the size of two city lots, this rainfall amounts to 25,000 cubic feet of water per year and weighs over one and a half million pounds. The heat given off when this amount of water is condensed from vapor to rain is equal to the heat given off in burning 50 tons of coal. This coal would cover the 100-foot-square area with a layer $2\frac{1}{2}$ inches deep. The heat given off in the air by the falling of a foot of rain over a given area is thus equivalent to that given off in the burning of a layer of coal an inch thick. For an annual rainfall of 30 inches on a 160-acre farm the coal equivalent would be 32,000 tons. Thus it appears that enormous amounts of heat are distributed by the earth's vapor-heating system.

Because the direction of flow of the ocean currents is controlled by the form of the continents, the heat which they distribute is delivered to areas thus determined. London has a mild climate, due to the Gulf Stream, while Labrador—no farther north—has a very cold climate. Sweden and Norway are at the latitude of Greenland; yet they have a habitable climate, while Greenland is bleak and ice-covered.

The heat of the sun also controls the distribution of rainfall. Warm air absorbs much moisture. When moisture-laden air is cooled, the moisture condenses and falls as rain. The direction of the

major currents of air is controlled by temperature and also to some extent by the elevation of the land. When warm moisture-laden winds come to a mountain range, they rise and are cooled and drop their moisture burden as rain. The prevailing westerly winds of our west coast thus meet the Coast ranges and the Sierras and lose their moisture. As they drop down the eastern slopes of the mountains and warm up again, they absorb what moisture is available and so produce the desert east of the Sierras. This case illustrates the cause for regions of heavy rainfall and of scant rainfall all over the earth. Deserts exist where the prevailing winds are growing warmer and thus increasing their capacity to evaporate water. Moist climates are formed where the prevailing winds are cooling and losing their capacity to hold water and so are obliged to let the moisture fall as rain.

The distribution of heat and moisture over the face of the earth by the ocean currents and the winds gives us the various climates we find today. The shape of our continents and their elevation are important controlling factors. These same factors have controlled climates in all past geologic eras. The factors have changed with the rising and sinking of the land areas. Changes in outline of the continents have changed the direction of

ocean currents. As mountains have been uplifted or worn down, their effect on winds has been great or little.

The usual climate of past geologic ages has been characterized by more uniform heat distribution over the face of the earth than exists today. Through much of their history the polar regions have been free of ice. In the rocks of Spitzbergen we find coal beds which were probably the product of a climate approximately as warm as that of Florida at present. These long periods of warm climate occurred in periods of low elevation of the continents, when the oceans spread over their lower lands and ocean currents had an opportunity to carry more heat to northern regions, and when there were few or no high mountain ranges to interfere with the air currents.

The periods marked by the rise of the continents to higher elevations and the building of mountain ranges—such conditions as we are living under—are those characterized by colder times and by definite zones of climate, from polar to tropical. The rise of continents and mountains seems to have acted on the earth's heat-distributing system much as shutting off a valve in a hot-air or hot-water pipe acts on our household heating system. If the heat carried by the warm winds and ocean currents from the equatorial belt is shut off from

the regions closer to the poles by the rise of the land, those regions get colder and stay colder until the heat is again given access by "the opening of the valve."

While the distribution of heat over the earth has been generally more uniform in past ages than it is today, the distribution of moisture has always varied. All through the long past, the rocks tell us, there were desert areas and well-watered areas. The facts we find today were true in past ages. Where winds got warmer as they travelled over the land, they absorbed moisture and made the land dry or even desert. Where they got cooler as they travelled, they deposited their moisture and produced well-watered land.

Where we find salt deposits in the rocks today we know that desert conditions must have prevailed when those sediments were deposited. Thus we know that parts of New York, Michigan, and the great area of salt deposits in the southwest were deserts in bygone ages.

Where we now find coal beds we know that the climate of the areas must have been, at that time, moist enough to foster the luxuriant growth of vegetation which produced the coal. Thus we know that in the ages when coal was laid down, a great area extending from Pennsylvania to Kansas and from Michigan to Alabama possessed

a well-watered climate, which produced great swamps filled with profuse vegetation.

The extremes of climate in past geologic periods have varied both in time and in place. In rainfall there have been variations from the most arid desert conditions to those of the heaviest rainfall. In temperature there have been variations from times of equable distribution of semi-tropical heat all over the earth to times when frigid cold prevailed over large areas and produced great ice sheets covering half a continent. There have been at least four of these great glacial periods. All of them were of relatively short duration when compared to the long periods of warmer and more equable climate.

The last glacial period was the "recent" one, described in the following chapter, which began perhaps two million, perhaps a half-million years ago. Vestiges of this still persist in the polar ice caps that attract explorers to these last great unknown parts of the earth's surface. The ice sheets covered northeastern North America and northwestern Europe. Strange as it may seem, Alaska and Siberia were barely touched by these continental glaciers.

From man's point of view the most important of the probable effects of the chill climate was the rise of mankind to domination over all other forms

of life. The development of a brain fitted him to cope with the cold, which in turn quite probably stimulated his further development by providing new difficulties for him to overcome.

Similar stimulation of the development of a new dominant race of beings by a general change to cooler climate we also find earlier, about sixty million years ago. The mountain ranges and continental elevations of that time were much less marked than those of the present, but nevertheless were sufficient to produce a climate cooler than that which characterized the main part of the Mesozoic Era. This cooling of the climate did not go far enough to produce a glacial period, but it almost certainly aided in the downfall of the dominant living beings, the reptiles, and in the rise of a new dominant type, the warm-blooded mammals.

Going back still farther, to the close of the Paleozoic Era about two hundred million years ago, there was a second wide-spread glacial period. Its deposits are found in the southern hemisphere, in South America, Africa, Australia, and other places. Some of the great ice sheets reached nearly to the equator. The elevation of the continent to a greater height above sea level and the uplifting of the Appalachian Mountains dried the swamps in which the coal deposits of the Car-

boniferous Period had been formed, interfered with the distribution of equatorial heat by wind and ocean currents, and compelled the swamp-dwelling plants and animals to adapt themselves to a life under drier conditions or perish. Out of the spore-bearing plants developed the seed-bearers, and the water-dwelling amphibian animals were superseded by the land-dwelling reptile type, the great dinosaurs of the Mesozoic Era.

A third great glacial period occurred shortly before the beginning of the Paleozoic Era, probably five hundred and fifty million years ago. It was followed by the development, in great abundance, of animal life with hard shells, the shell-fish type of beings. Whether the cold aided this development or not we do not know.

The fourth and most ancient known great glacial period is believed to have occurred about seven hundred million years ago, but the evidence is sketchy and unsatisfactory. It is mentioned only to point out that at intervals of about a quarter of a billion years there have occurred great ice ages with zonal distribution of climate like that of the present time.

Even the greatest extremes of climatic conditions for the whole billion-year record have been within the narrow limits that are necessary for the continued existence of living beings. The

occurrence, within these grand cycles, of shorter cycles of less extreme variation and shorter period is indicated by the evidence found in the rocks. In the deposits of the last ten thousand years—since the last glacial period—we find that there have been cycles of a few hundred to a few thousand years in length. In Sweden DeGeer has found that certain plants once lived several hundred miles farther north than they do at present, a fact which indicates that the climate was warmer then than now. The retreat of the last remnant of the ice, because of a faster rate of melting during this warmer time, was more rapid than it was later on. During the period when the last ice sheet covered parts of Wisconsin and Michigan, there were alternate colder and warmer cycles in which the ice edge readvanced and then retreated again.

Whether the post-glacial warmer period mentioned indicates that the climate is going to continue to get colder and that the ice is coming back in a few thousand years we do not know. If the ice does return, its coming will be so slow a process that our descendants will have ample time to adjust their lives to the changed conditions. The general indication is that there remains before us a long time—perhaps a hundred million years—of gradual wearing down of our high mountain ranges

and settling of our continent, with a consequent warming of the climate. This would mean that the distinctness of our present climatic zones would gradually disappear and a uniform semi-tropical or temperate climate would once more prevail over the whole earth.

CHAPTER VII

THE GREAT ICE AGE

As long as a hundred and fifty years ago a very puzzling fact had been observed in the northern part of our country and in Canada. Over most of that region men noted that there were numerous boulders and pebbles of granite and other rocks wholly unlike the local sandstones, shales, or limestones which made up the outcropping ledges of solid rock in quarries and hillsides.

These boulders, found promiscuously on mountain top and in valley bottom, were called "strangers" or "erratics" because it was recognized that they must have been carried in from some distant region where such rocks occurred in ledges. What agency could have transported these strangers it was difficult to imagine.

The true solution of the puzzle was reached in 1840 by the great Swiss naturalist, Louis Agassiz, later an American citizen and a great teacher at Harvard. His familiarity with the mountain glaciers of his native land and with the deposits left behind as they melted enabled him to recognize

that the "stranger" boulders and pebbles together with their associated deposits were the results of glacial action. But it was not until the time of the Civil War that this explanation was generally accepted by scientific men in this country; even in the early nineties an eminent geologist refused to believe in the existence of the great continental glaciers.

The recognition of the truth of the Agassiz explanation opened up a most fascinating field of study for all those who were interested in geology in the region north of the Ohio and Missouri rivers. This study is still in progress, and much remains to be done before all the facts of the great ice age are thoroughly understood.

It is known that the ice age was a period of unusual cold but it is doubtful if it was as cold as usually imagined. Probably it was not arctic in its extreme low temperature. Quite likely it was comparable to a present-day Canadian winter, through which men and animals live in comfort. It has been estimated that if the *average annual* temperature in the northern part of North America were to drop a total of 7 to 15 degrees F., a drop less than the ordinary daily change in our thermometers, another great ice age would result.

Supposing that such a drop were to occur, let us see what would happen. The snow would

begin to pile up, as it did in the last ice age, on the gentle elevation known as the Laurentian Upland, east of Hudson Bay, and on the similar gentle upland west of Hudson Bay, the other center from which the great continental ice sheet radiated in the last glacial epoch. After a few years of this colder temperature the snow would have accumulated to such an extent that the summer heat would not be sufficient to melt it away. Thus would accumulate, after many years, a considerable thickness of snow which, by alternate freezing and thawing, and by its own weight, would be compacted into ice. As the ice grew in thickness, its weight would increase until it became so great that it would cause the margin of the ice to shove outward toward the surrounding territory. There, too, the winter accumulation of snows would not be melted during the summer, and so accumulation would continue, gradually shoving out on all sides and finally encroaching upon regions where previously the summer melting had been enough to do away with the winter snowfall. In this way, slowly and over thousands of years, the ice would gradually increase in thickness and, at a most leisurely pace, continue to spread farther and farther until finally a limit would be reached where the summers were warm enough to melt both the winter snowfall and the ice that was slowly shoving in from the north.

This is exactly the way in which the great ice ages of the past came about. The ice moved out from the Laurentian region east of Hudson Bay and also from the Keewatin center west of Hudson Bay. At its extreme advance the ice sheet occupied practically all of the territory north of the Ohio and Missouri rivers and covered that vast region with a great thickness of ice.

There is little to tell us the maximum thickness the ice attained, although it is estimated that it was at least two miles thick over much of the glaciated region. We do know that it pushed its way over high mountains as well as lowlands, and that over the tops of the mountains there must have been a very considerable thickness of ice.

This tremendous thickness piled a weight of many tons—at least 300 to 400—on each square foot of surface. When the ice moved, this weight was sufficient to cause it to scrape away the soil and loose rocks which lay under it. The rocks that were moved along by the ice scratched and grooved the solid rocks beneath, and wore them down and polished them, with the result that almost everywhere in the region covered by the ice any flat, bare rock surface shows groovings and scratches which mark the direction in which the ice was moving. These scratches can be seen in Bronx Park in New York, in the Adirondacks,

in many thousands of places in New England, and in all the states to the west. As a result of careful mapping of these marks the directions of movement of the ice have been worked out, so that we know quite accurately just how the ice was moving for a short time before it melted away. Oftentimes we find earlier scratches cut at an angle by those of a later movement; thus we know that the direction was not always the same throughout the whole period of advance of the ice.

When the front of the ice sheet melted back, the rocks and soil which it had moved along in its course were, in general, left in a jumbled mass commonly called glacial drift. When this material was carried by streams from the melting ice, it was sorted into beds of sand and clay and gravel in accordance with the volume and velocity of the stream, just as gravel beds, and sand and clay beds are made today from the material which rivers are carrying along to the sea. If the water was swift and the stream large, only large pebbles were dropped. If the speed was less, smaller pebbles accumulated, and the finer material was deposited only where the water slowed down or became almost stagnant.

The movement of the ice was not at all rapid. It was probably measured in feet per year rather than in miles. The location of the southern edge

of the ice varied. When a series of colder years occurred, the ice front advanced. When a series of warmer years came along, the rate of melting at the front was greater than the rate of advance, and consequently the ice melted back. During both the advance and the retreat of the great ice sheet, the movement was undoubtedly characterized by an intermittent series of minor advances and retreats of this sort. The position of the front could be considered always as the result of the battle between the rate of melting and the rate at which the ice was pushed forward. During retreat, melting was the victor; during advance, the rate of movement of the ice overcame the rate of melting.

Before the coming of the ice, that part of the United States north of the Ohio and the Missouri was much like the area south of those rivers today. West from Minnesota and Iowa were plains; east was a fairly rough, hilly country. A sample of how this hilly country looked was left us by the glaciers, for they failed to cover the southwest quarter of Wisconsin. There we find the upland five hundred feet above the valley bottoms, with most of the hillsides too rugged to cultivate. There the farms are chiefly confined to ridge top and valley bottom.

When the great ice sheet moved over hilly

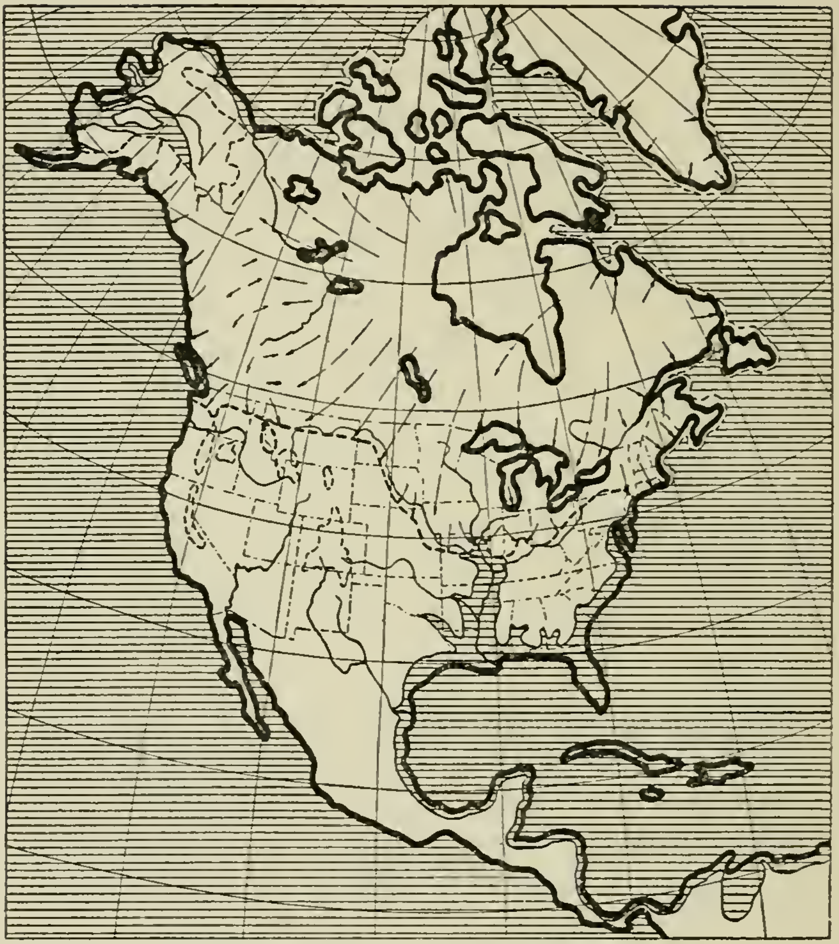

FIG. 8. The present outline of North America is the heavy line. The arrows show the directions of movement of the great glaciers that covered the northern part of the continent, and the dashed line shows the position of the extreme advance of the glaciers. The horizontal lines show the area covered by the sea at that time—not over two million years ago. The ice melted away from the United States about twenty thousand years ago. After Bayley Willis.

country, it rounded off the hill tops and filled in the valleys. Where it found steep slope and rug-

ged country, it left gentle slope and the beautiful rolling country which characterizes the area from New England to Iowa. Over this rolling country it deposited the thick layer of rich soil which it had brought with it from the north. This transfer of soil from the far north has been fittingly described as the "greatest real estate transfer on record." To it, in part, we owe the richness of our soils in the northern Mississippi valley—the world-famous "corn belt" and much of the wheat and dairy regions.

In filling up the old valleys the glaciers did a pleasingly artistic and irregular job. They did not smooth the country to a monotonous level. They left elevations and low places. The latter they generously filled with the abundant water from their melting ice to make the tens of thousands of beautiful lakes that add so much to the attractiveness of the landscape from Minnesota to New England.

In its progress over the valley of the St. Lawrence river the glacier changed it from a river valley into the greatest inland waterway in the world—our five Great Lakes. Had there been no ice age there would be no Great Lakes as we know them today.

At present Canada and the United States are contemplating the expenditure of several hundred

million dollars to make a hundred miles of the St. Lawrence river into navigable water. The great ice age did a far better job on more than a thousand miles of waterway in the Great Lakes, and it cost us nothing.

Why should a region with a temperate climate be subjected to a change which brought about an invasion of the ice from the north? Once the ice had invaded the territory, what brought about its retreat? The first part of the answer we know—that the temperature must have been lowered for a long period of years and then raised. The second part—*why* the temperature should have been first lowered and then raised—we do not yet know. This last ice age is not the only one that has left evidence of its existence. As pointed out in Chapter VI, such glacial periods have occurred all through the billion years of the earth's history. The last great ice age is itself divided up into four or five separate great advances and retreats of the ice. We cannot be certain, but it is quite probable that between each of these four or five the climate became as warm as it is now. In one interglacial period we have good evidence that the climate was warmer than it is at present.

There are some facts which have a bearing on the cause of the glacial period. We know that the amount of heat which the sun gives out varies

from time to time. When the face of the sun is partly obscured by sun spots, the amount of heat given out is less than at other times. We also know that the amount of heat received by the earth varies for another reason. When the earth is closest to the sun in its annual path, more heat is received. When it is farthest away, less heat is received. Another condition that probably has some influence on the origin of glacial periods is the state of the atmosphere. Part of the heat received from the sun is radiated back into space by the earth. The amount radiated depends upon the atmospheric condition, and there may have been slight variations of the atmosphere which would have aided somewhat in lowering the amount of heat retained by the earth.

Another factor that must have had some bearing on bringing about the glacial period is the distribution of heat over the earth's surface. The great air currents and ocean currents act to distribute the heat of the earth. Since the shape and elevation of the land have changed in important particulars in past geological time, they must have caused profound changes in the climate.

After taking notice that these various factors can have some influence on the occurrence of glacial periods, we have gone about as far as is profitable here, considering the present state of

scientific knowledge. It still remains for science to make an adequate explanation of why, at various long intervals throughout much of the recorded history of the earth, we have had great ice ages.

In terms of geologic time the last great ice age is very recent, and yet the last vestiges of this ice were gone about eight thousand years ago. The last of the great glaciers disappeared from the United States probably twenty or thirty thousand years ago. In dealing with geological time a thousand years is a small unit, and it is difficult to read the record within the limits of such a short period.

One very interesting geological clock that we have to measure the time since the retreat of the ice is Niagara Falls. A most instructive history has been studied out in connection with this, which space will not permit describing here. It is sufficient to say that by observing the rate of recession of the Falls it has been possible to estimate fairly accurately the length of time it has taken the river to cut its gorge. This gives a measure of the time during which Niagara River has been at work, for the river, of course, could not exist until after the ice had melted away from the St. Lawrence valley.

Another interesting geologic clock is found in the ancient lake beds of Sweden. Here very careful study by the eminent Swedish geologist, Baron DeGeer, has disclosed the fact that the annual layers of mud deposited in these lakes can be identified. By careful search and counting he has found that the European ice sheet completed its retreat through that district about eight thousand years ago.

The time of the beginning of the advance of the last ice sheet is only a matter of estimate, for the evidence that the ice made as it went along was destroyed by its own advance. When it comes to estimating the time at which the previous three or four great advances of the last glacial period took place, our ideas become still more indefinite. The total time occupied by the whole of the recent glacial period has been estimated as varying from several hundred thousand years to a million or more. Measured in the units in which we are accustomed to think, this is a length of time entirely beyond the capacity of our minds to understand. Measured against the billion or more years of the history of the earth, it is a very minute portion, and consequently geologists speak of the whole of the last glacial period as a recent geological event.

The studies of the glacial period which geologists have made have been very largely for the purpose of finding out interesting facts, with no particular idea of discovering things that might be of use or value. As usual in such cases, however, work that began as purely scientific has proved to be of great practical value. The study of the formation of the gravel and sand deposits formed by the streams from the melting ice has been turned to good use in the northern states in connection with the building of highways. Crews of glacial geologists have been sent out to prospect for such deposits of sand and gravel as might be located close to a contemplated road improvement, in order that the expense of hauling the material long distances could be avoided. Many millions of dollars have been saved in the last ten or fifteen years by this application of what previously had been merely an interesting field of scientific knowledge.

There are many ways in which it is evident that the effects of the great ice age are of benefit to those of us who live in the region where it did its work. I have mentioned that we owe the existence of our Great Lakes to the work of the glaciers. On these lakes we carry coal and wheat and iron ore to market for a fraction of what the railroad rate would be. Our blast furnaces and steel mills

make iron and steel at a correspondingly lower cost. Consequently, we build our railroads cheaper than we otherwise would, and our freight bills are lower than they would be if there had been no great ice age. With this cheaper steel we build our skyscrapers and our homes for less money. We ride in automobiles that cost us less. We drive these automobiles on concrete roads that are cheaper because of the abundant glacial deposits of sand and gravel.

The glaciers were largely responsible for the wonderful richness of the soils of the northern part of the Mississippi valley; we have more farms, and they are more productive than they would have been without the work of the glaciers. These fine farms and the wealth they create make possible larger and more prosperous cities, with more factories and a greater laboring population than could find a livelihood if there had been no great ice age.

It is easy to see how the ice age of thousands of years ago left us a legacy of almost incalculable value. Although these great glaciers were no doubt unpleasant neighbors in their time, they have nevertheless left to us who live in their pathway many things which should make us thankful that there was this great and only partially understood event in the geologic history of the region where we live.

CHAPTER VIII

GEOLOGIC RESOURCES WE USE

When geologic resources are mentioned, we are most likely to think of the precious and useful metals, gold and silver, copper, iron, lead, and zinc. While these are greatly needed in our civilized lives today, the human race lived for millions of years before it learned to put any value upon them.

If we look upon geologic resources from the viewpoint of their fundamental necessity to human life, we must revise our notions of what they are. We must include all the various needful things that this earth affords us, whether they come from "the heavens above, the earth beneath, or the waters under the earth." In such a list of resources the heat and light we daily receive from the sun become of vastly greater value than the gold or the iron. If the sun were blotted out and our supply of heat and light cut off, our lives would end abruptly. Similarly, if the oxygen were removed from the air we breathe, death would overtake us in a few moments. If all the water were taken from the surface of the earth, most of

the very substance of our flesh would be gone. Yet light, heat, air, and water are geologic resources. They are so abundant that we rarely think of them. Fortunately for us their supply, from the human point of view, is inexhaustible.

In arid regions, it is true, water takes on a premium value because there is locally not enough of it. Even in the great well-watered Mississippi valley water is getting to have a money value and a life value of great importance because it is the limiting factor to growth of population. Chicago must spend millions reversing the flow of a river to protect the purity of its drinking water. Every city and village must spend relatively large sums to secure and protect adequate water supplies, to make sure of a sufficient quantity of this necessary geologic resource. Of vital importance, but too little appreciated by our people, are the studies of our water resources now being carried on by public geologic and engineering organizations.

The most important use of water, of course, is in our homes. We must have pure water for drinking and cooking and other household purposes. The use second in importance is for industrial purposes. Most of our productive industries require water, some of them in very large quantities, and consequently must be located where sufficient water of proper quality is available.

The use third in importance is not so readily apparent; probably it is irrigation. The uses of our rivers for power development, for navigation, and for esthetic value, such as the preservation of scenic water falls, are all of less importance than the first three named.

For our convenience in discussing them, geologic resources may be roughly divided into two grand divisions. The first includes those we have just discussed, heat, light, air, and water—common things we seldom think of as geologic resources. So far as we can look into the long geologic ages of the future, there is every reason to believe that there always will be sufficient of these for all human purposes. These resources may not all be distributed as we would like, but living beings need never fear that they will use up any one of them and produce a scarcity.

The resources of the second grand division are, in many cases, of the kind that can be used up to the point of scarcity. They may be classified in order of their importance as: 1) soil, and mineral fertilizers; 2) fuels; 3) metals; and 4) non-metallic mineral resources. Upon the soil as a geologic resource we must depend for all our food except the relatively small part that we get in fish from the waters. All our grains, fruits, vegetables, and meats are directly or indirectly soil products.

Our clothing—cotton, wool, leather, and silk—is all from the soil. Timber also is a soil product.

Like many geologic resources soil is exhaustible. After it is deprived of its natural protecting coat of forest or grass and subjected to cultivation, it is much more readily eroded. Each year rains carry millions of tons of it into the rivers to be transported to the sea. Many thousands of acres are thus destroyed annually through cultivation and careless farm operations. Though much of this waste could be prevented at little cost, some of it is unavoidable.

Another cause of soil exhaustion is continued cropping. Every pound of grain, everything in fact that grows on the soil, carries its toll of mineral matter with it when it is shipped from the farm. While all soil products are composed chiefly of water, carbon, and oxygen—materials which the plants get from the rainfall and the air in unlimited quantities—they also require small amounts of minerals. Of these the most important are nitrates, potash, and phosphorus, which occur in soils in small amounts as the natural products of rock decay. The total amount of phosphorus present in good soil is sufficient to supply only from one hundred and sixty to two hundred and fifty crops. Long before the supply is exhausted completely, it is reduced too low to support profita-

ble crops, and farms become economically unproductive. When you read of an abandoned farm, the chances are very great that before the farmer abandoned it he had exhausted its soil by removing much of these mineral constituents essential to soil fertility and had failed to replace them.

Thus the very soil, so necessary to our existence, is a geological resource which can be exhausted with relative rapidity. If it is allowed to be wasted by erosion or if its fertility-producing mineral constituents are not replaced as the crops take them out, it will soon cease to produce in sufficient abundance for our needs. To replace these minerals is rather expensive. Nitrates must be shipped from Chile, manufactured by expensive processes from the nitrogen of the air, or restored to the soil by growing clover and alfalfa, plants that take nitrogen from the air. Potash must be shipped at a high cost from Germany or France, or from recently discovered deposits in our own southwest. Phosphates are found in considerable abundance, but they are expensive to mine and prepare in suitable form for use on the land and to transport for the long distances necessary. Yet if our soils are to continue to produce, these things must be done.

Mineral fuels—coal, oil, and gas—are next in importance as geologic resources. The part they

play in our lives is vastly greater than we ordinarily appreciate. From our personal experiences we are apt to think of their use to us in terms of coal to heat our homes and gasoline to run our automobiles. These uses are important, but others overshadow them.

One of the notable things that distinguish our civilization from civilizations that preceded it is our use of mechanical power—steam and electricity. All earlier cultures were dependent on the muscle power of men and beasts. Without important exception they were characterized by slave labor. Our present civilization has supplanted slave labor and has tremendously multiplied the power of muscles by the invention of machines and the use of power to drive them. It has been estimated that each man, woman, and child in the United States has at his service, producing things for his welfare, the equivalent of the muscle power of over eighty human slaves. While a most necessary part in this progress is the use of metals to make the machines, these mechanical slaves that serve us, it is obvious that without the mineral fuels we would still be dependent, mainly, on the power of muscles.

Because of these resources and the use we make of them in production and transportation, the average working man has in his dinner pail an

orange from Florida or California, or a banana from Central America. The bread and meat in his sandwich are supplied by wheat fields and cattle ranges a thousand miles away. Someone has computed the total miles that the ingredients of an ordinary meal have travelled, and has found a most staggering total. I will leave you to figure this out for yourself as a lesson in the value we get out of the mineral fuels that make all this possible. It is because of them that the common citizen of today enjoys more of the material things of life than the wealthiest man possessed a hundred years ago.

Of our metallic resources iron is by far the most important. It is this metal that enables us to make the unprecedented use of mineral fuels that differentiates our present civilization. All our factories are filled with machines of iron and steel. All our transportation agencies, ships and railroads, trucks and busses, are made possible by the abundance and cheapness of iron. Copper, lead, zinc, and aluminum are able and invaluable assistants to iron in making possible an effective use of the tremendous energy stored in our coal beds.

Each metal has properties that give it special utility for certain purposes. Iron is most useful because of its great strength and hardness and

because of its ability to take on special degrees of hardness on being tempered. It is fortunate for us that iron is the most abundant and therefore the cheapest of metals. Its strength, hardness, and cheapness make it the ideal metal for railroad rails, for bridge and skyscraper construction, for our machines and implements, and for the myriad of other common uses we find for it.

Copper is the basis of our whole electrical industry because it conducts electricity better than does any other common metal, because it is ductile and readily drawn into wire, and because it is one of the most durable of metals, resisting corrosion much better than iron. Its capacity to alloy readily with zinc and make brass gives it a multiplicity of added uses. A large part of the moving bearings of machines are made of brass because thereby friction is reduced.

Lead is employed for many purposes. The largest amount is used for covering the great electric and telephone cables that run under our streets or along the pole lines. Nearly as much is used for storage batteries for our automobiles. The consumption for paint requires another important amount. Roofing, pipes, ammunition, and other needs take much of the remainder of this metal.

Zinc has been known as a metal for only a little

over a century. To its capacity to form a corrosion-resisting coating on iron and steel is due its greatest use. Nearly half the amount we consume is required in the manufacture of "galvanized" sheets, wire, and other forms of iron that are exposed to the weather. The next largest use is for alloying with copper to make brass. These uses consume three-quarters of our zinc.

Other common metals, used frequently but in much smaller quantities, are aluminum, nickel, tin, chromium, gold, and silver, as well as many others that are quite unfamiliar to most of us.

The relative values of the common metals are presented interestingly in a recent article by John A. Gann, in which he gives the approximate cost per cubic foot as follows:

Nickel	$200
Tin	100
Copper	40
Aluminum	38
Magnesium	30
Lead	25
Zinc	15
Iron	5

The use of our mineral fuels and metals has increased with almost unbelievable rapidity in recent years. If we consider the total amount used between the time our country was first set-

tled and 1928, we find that only 22 per cent of the coal mined was used before 1900 and 78 per cent afterward. For oil the figures are 4 per cent before 1900, and 96 per cent afterward. Of the total electric power 2 per cent was used before 1900, and 98 per cent from 1900 to 1928. Of the metals there has been used since 1915 approximately as much as was used in all our previous history.

TABLE 2

Use of Metals in the United States

Metal	Pounds Used per Person		Per Cent of World's Total Used in the United States	
	In 1900	In 1930	In 1900	In 1930
Iron	387	715	34	42
Copper	5	16	33	47
Lead	6	12	28	41
Zinc	3	8	19	33
Aluminum	0.1	2	51	45

Table 2 shows the average number of pounds of metals used for each man, woman, and child in this country and also the percentage of the world's total production that we use. When we consider the small fraction of the world's population that lives in the United States, only 6 per cent, and then find in this table that we use about 45 per cent of the world's total production of metals, it is

easy to appreciate that we have very much more than any other people to use and enjoy.

We are consuming our stores of mineral fuels and metals so fast and at such rapidly increasing rates that there is reason for much critical inquiry as to the length of time they will last. Nature has been accumulating the coal and oil and the ores of the metals through all the billion years of the geologic past. When a ton of coal or of metallic ore or a barrel of oil is removed from nature's store house and used, it is not replaced. It is inevitable that the time will come when the last ton will have been mined out and used. These resources are what the economists call wasting assets.

Since these wasting assets are so vital to our present civilization, it is extremely important for us to know when the end of our supply will be reached. The various scientists of official geological surveys and engineers and geologists working for mining companies have in recent years combed the earth to measure these resources. From their studies we have reasonably accurate ideas about the amounts available. The supply of coal in the world is probably sufficient to last for several hundred years at the present rate of consumption. We are particularly fortunate in the United States, for we have 60 per cent or more of the world's total supply. Coal will probably

last us longer than any other of our wasting assets.

Oil and natural gas are much more difficult to estimate than coal. Some oil geologists believe that the available supplies in the United States will be largely used up in ten years. Others believe we will succeed in finding enough to keep us going for twenty or thirty years. But in either case the time is most pitifully short in comparison to the long period we hope to see our present civilization continue.

Iron also has a story quite different from that of coal. Of the rich ores we now use, which contain about 50 per cent of iron, our supply is quite accurately known. In the greatest of our iron ore districts, the Lake Superior region, which now supplies about 85 per cent of the iron produced in the United States, the supply of present grades of ore is sufficient to last for only about twenty-five or thirty years. Then we will be obliged to use much lower grade material containing only about half as much iron. When we learn how to use these lower grades, the supply will last us several hundred years, possibly a thousand. But our supply of iron will cost us far more than it does at present.

We do not know so much about the other important minerals as we do about coal and iron ore.

Known copper deposits will last us perhaps another century or two at present rates of consumption. The supply of lead and zinc ores is not so well known as the supply of copper. It is not likely that these will last as long as copper.

Of all the metals the one that occurs most abundantly is aluminum. The common clay we find all about us contains from 15 to 25 per cent. We do not yet know how to secure the metal cheaply from this source, but we must hope that science will find a way before our lack of metals becomes too severe a handicap to our metal-using civilization.

The last great class of mineral resources is the non-metals. These include a long list, only the chief of which are named.

List of Non-metallic Mineral Resources

Abrasives	Gems
Corundum	Gypsum
Emery	Limestone
Grindstones	Mica
Millstones	Phosphate Rock
Asbestos	Salt
Asphalt	Sand and Gravel
Building Stones	Silica
Cement Rock	Slate
Clay	Sulphur
Graphite	Talc

Some of these are common and widely used, such as salt, building stone, cement rock, clay,

and gypsum. Some are uncommon and of relatively small use, although those small uses may none-the-less be of great importance to us. Others are in the class with gems, mineral resources without which the world could quite readily get along even though important industries are based on mining and marketing them. It is not beyond our imagination to believe that young men and young women would find a way to become engaged and married if all the diamonds should suddenly cease to exist. Most of the useful nonmetallic resources are found so abundantly that we do not need to fear that their continued use will produce a shortage of the supply.

When I contemplate the vitally important ways in which men of the present time are benefited by the earth's wealth of geological resources, I sometimes wish I were a great artist. I should like to dramatize this fact in a masterpiece of sculpture. I should present a group of four figures. As we look at this group, the first figure, representing the *Earth*, would be a heroic female figure facing to the right with open hands outstretched toward *Man* in an attitude of benevolent giving. The next two figures, back and to the right, between Earth and Man, facing the observer, would likewise be of heroic size, side by side, each with an arm about the other to indicate their wedded

inseparability, a woman representing *Science* and a man representing *Industry.* The fourth figure would represent *Man,* standing at the right of the group, facing the others, in an attitude of humble gratitude for the rich gifts conferred upon him, of acknowledgment of the responsibility which their acceptance lays upon him.

In the marble at the feet of *Earth* I would carve representations of the wealth of her resources, forests and fertile fields, rivers and seas, oil fields and ore deposits. At the feet of *Science* and *Industry* I would carve representations of factories, mines and furnaces, mills and dams, railways and ships, and electric lines for power and communication.

Then if my genius would permit I would endow them with words and let them speak to all men:

Earth: "I am the Earth—the mother of mankind. From *ignorant* man I long withheld the wealth of my resources. Now, through Science and Industry, I give of them freely and gladly to *enlightened* man."

Science and Industry: "We are Science and Industry—inseparable—the knowledge of things and of the forces and processes that mold them. We pass on to the race of man the bounties of Earth. We take the products of her rivers and seas; we take the offerings of her soil—the foods,

the fibres, the forests; we take the wealth of her mines—the stone, the clay, the coal, the oil, the ores of metals. From these we fashion all things for the need, the comfort, and the health of man —his food, his clothing, his warmth and shelter. We do more. We give him light and power and the means of transporting his wealth and of transmitting his thought from end to end of the world. These manifold services we render so that all may have in abundance if man will use with wise mind, just heart, and careful hand the power and the wealth we offer."

Man: "I am Man. From my mother, Earth, through my benefactors, Industry and Science, I have received all these gifts for my happiness and advancement. I have wealth; I have power. Dominion is mine over land and sea and air. May it be granted me to realize the truth that these are mine only so long as I use them with due wisdom."

CHAPTER IX

WHAT GEOLOGISTS HAVE LEARNED IN THE LAST CENTURY

A HUNDRED years ago the science of geology was, like most other sciences, in the earliest stages of its development. Its most capable observers had no suspicion of the existence of a great ice age. They had but recently begun to agree on the fact that some rocks were of igneous and some of sedimentary origin. Hutton had just made his revolutionary discoveries (See Chapter I), but they were not yet generally accepted. The idea that our present land areas had many times been alternately above and below sea level was just beginning to be recognized as an inescapable conclusion from the evidence in the rocks. The science of chemistry had not developed sufficiently to determine completely for geological observers the composition of rocks and minerals.

Great areas of all the continents except Europe were unknown to civilized man. World maps of that time were, to quite a large extent, beautifully artistic products of the imaginative draftsman. The wide blank spaces of the unknown areas were

filled with dignified scrolls and pictures of legendary monsters. Few books or pamphlets had been published dealing with geologic observations.

Darwin had not come upon the scene with his epoch-making recognition of the evolution of living forms. Most truly might it be said that from the viewpoint of the knowledge of geology the earth "was without form and void."

Now all this is changed. Man's curiosity about the earth he inhabits has driven him to explore its farthest corner. Geologists have visited and studied and described its surface and its resources, so that now we have a fair amount of information about even the most remote and inhospitable country. Today it would require a vast library to house all that has been written about the geology of the world.

A hundred years ago our civilization had only begun, in most primitive ways, to use the mineral resources of the world. Mechanical power from mineral fuel was practically unknown. A steam engine was a curiosity worth a long journey to see. The use of iron and steel was so meager that transportation was most primitive. The slow, horse-drawn wagon and the sailing vessel were the only common agencies for moving freight. From far countries only the most valuable of commodities could bear the cost of transport, so commerce was

chiefly in such things as tea, spices, or silks, with relatively little of cheap foodstuffs. It required a typical shipload of tea to supply material for the famous Boston Tea Party.

Great cities such as we have today could not have existed a hundred years ago. The cost of transporting food for an inland metropolis like Chicago would have been prohibitively expensive. London was the only city in Europe with over a million people, and these could be fed only because it was a seaport. Our growth in population is directly based on our use of the geological resources of mineral fuels and metals to make possible our modern transportation facilities. In providing knowledge of these much-needed resources, geology has performed adequate service.

For the first half or more of the last hundred years geologists, as well as other scientists, were interested almost wholly in discovering the great fundamental principles of science. Scientific interest, on the part both of scientists and of the educated public, was based on intellectual curiosity. The applications of science to material human welfare, to the providing of new things for people to use and enjoy, could not proceed far until the broad principles of science were first worked out. Only after these broad principles had been discovered and tested and found to be

true could they be used successfully in the more detailed *applications* which are of direct material benefit to us in our daily lives.

In this earlier period of development most scientists looked down upon the "money grubber," the man who wanted to apply scientific knowledge to practical uses and make money out of it. Thus there came to be a group of devotees of "pure science" who considered themselves much superior to the lesser group of devotees of "applied science." This division persists to the present, although the distinction has lost its sharpness, and most men of science now take pride in scientific work that is of immediate economic use.

Long study of the glacial period was necessary before the details of the way the great ice sheet moved and worked and melted away could be known sufficiently well for that knowledge to be applied to prospecting for glacial deposits of sand and gravel. When this stage of knowledge was reached, geological investigations were made by highway departments of various states and resulted in the saving of many millions of dollars in the cost of highway construction.

After intensive study of geologic materials valuable as ores had resulted in information helpful in finding new ore deposits, mining companies began to employ geologists. Now it is quite the usual

practice for a large mining company to maintain a geological force to help guide its prospecting and mining operations. Many large financial institutions employ trained geologists to examine for them the properties of mining companies to which they make loans.

Public utilities use geological knowledge of the resources of territories which they serve to guide them in estimating future business developments for which they may be called upon to provide. For this purpose many railroads and power companies have maintained geological departments or employed specialists to study mineral resources and possible developments of these resources into future business activities.

Oil companies use geological knowledge very extensively in their operations. Large forces of trained geologists are employed to study possible oil-bearing territory and to determine whether it is worth while to spend money for drilling. The rock layers penetrated in drilling are studied most carefully to guide the drillers to success in their operations. So effective has been the application of geology to oil development that the oil companies are at present plagued with a superabundance of oil, and our oil industry suffers temporarily from a serious over-supply.

The science of geology has served us very effec-

tively in working out the ways in which occur the mineral fuels, the ores of the metals, and the multiplicity of non-metals we need—building stone, lime, cement rock, phosphates, sulphur, sand, gravel, clays, salt, and others too numerous to mention here. The details of all phases of applied geology are being studied constantly, and each year finds us better equipped with understanding of the mineral resources which we use. Much, however, is still unknown and will continue to be beyond our understanding for generations to come. Geology offers almost unlimited opportunities for interesting work and for worthwhile, practical discoveries.

It is almost wholly during the last century that scientific studies have taught us to read the a-b-c's of the story in the rocks—not written by human hands, but given us as it was written by the hand of the Creator—the impressive story of the more than a billion years of the earth's history. The elements of this story we can now understand. Much more is still undeciphered and awaits study by generations yet to come. It will be a long time before geologists have learned to translate the x-y-z's of the details of the earth's history.

In this century of progress we have learned much about the way the earth must have originated from the sun. (See Chapter III.) We have learned

how to weigh the earth and measure the actual number of tons that make up its mass. We have learned how to count the years that it has existed in the general form and size in which we see it. (See Chapter IV.)

We have found that our earth is not the solid, immovable globe that was pictured by our ancestors a hundred years back, but that it throbs and vibrates and is changed by constant, slow movements. The interpretation of the records in the rocks has shown us that the sea deposited some of the materials we now find in mountain ranges, so we know beyond question that the areas where our high mountains are must once have been sea bottom. We have discovered how to read in the records that various parts of our great Mississippi valley have been below sea level a score of times or more. We have learned that volcanoes and earthquakes are, from the billion-year viewpoint, but minor and quickly passing phases of these grand movements that are constantly but slowly going on today all about us.

We have discovered how to study and unravel the complex structural story told by the folded, faulted, tilted, and overturned sea bottom deposits that we find in mountain regions. Careful observations with the magnetic compass have proved that the earth acts like a great steel magnet and

offer a strong suggestion that its interior core is actually of iron, a suggestion that is made almost a certainty by the weight of the earth and by the way it transmits earthquake waves—as though it had the rigidity of steel.

The long, painstaking study of the remains of living things found in the rocks—the life work of thousands of scientists—has enabled us to see clearly the outlines of the wonderful picture of the slow development of life from low forms to high. The revealing of many of the details of this picture awaits the efforts and studies of the future, but its general outlines are distinct and clear. These studies of living things suffice to tell us the relative ages of the rocks. They tell the oil geologist just which parts of the earth are worthy of further investigation to find oil, and which parts are worthless. They impart similar useful information to the coal geologist. They have made it possible to map the rocks of the whole world and place them in their proper age classifications as indicated in Table 1 on page 55.

A hundred years ago nothing was known of the way rocks were disintegrated to form soil. It required the patient investigation of many years to convince scientists that solid rocks could be dissolved slowly by rain water. It also required the parallel development of the science of chemis-

try to enable us to understand the processes of rock disintegration. Those processes work so slowly that convincing evidence of their capacity to affect rocks was not apparent until long years of careful study and observation had been devoted to the subject. As more was learned of the effect of water on minerals and rocks, the reasons why bodies of valuable metallic ores had been formed began to be understood. The effect of waters, both cold and hot, on the deposition of valuable ore deposits has been the object of intense study for the last half-century. While we have learned much that helps us to find and utilize these ores, there still remains much more than we yet know which must be found out by future study.

In this century of scientific progress we have learned how to read something of the record which the climates of past geologic ages have left in the rocks. Unquestionable evidence has been found that areas of desert and of abundant rainfall, areas of cold climate and of hot, such as characterize our climates today, have existed all through the past as far back as the rock record is translatable. Climates have changed in every region. Heat and cold, dryness and moisture have succeeded each other in a long repetition of cycles. Our now frigid polar regions have been warm enough to support semi-tropical life. Great glaciers have existed in equatorial regions.

With all our knowledge of these interesting and important facts, deciphered by laborious study of the rocks, we know only a small fraction of the things that will be known in the future. Probably the outstanding general fact we have learned is that, throughout all the long record, conditions of land and sea, temperature and rainfall have been much as we see them today, suitable for the continuous existence of living things. Upon the basis of this billion years of constant, uniform behavior of this old earth of ours, we are amply justified in extending the rule that has prevailed in the past far into the future, not merely for thousands of years but for hundreds of millions.

CHAPTER X

WHAT OF THE FUTURE

FROM our pardonably egotistic point of view the most important development of the billion years of the earth's history is mankind. We are the heirs of all the long, slow evolution of living things. We possess within ourselves all the best things that this progress toward perfection has developed to the present time.

Let us review briefly the outstanding features of this development. At the beginning of the Paleozoic Era, more than a half-billion years ago, the higher types of animals had eyes and the necessary accompanying nervous system and brain to enable them to see. They had a well-developed digestive system and a complex muscular development. Toward the middle of this era occurred the great invention of an internal jointed skeleton with a flexible backbone as its principal feature. At the end of this era came the development of lungs which enabled the highest forms of animals of that day to leave the water and live on the dry land and thus to conquer a hitherto unoccupied

territory. A hundred million years later other major improvements occurred—the development of warm blood and the capacity to bear living young and nurse them through a period of infancy. All these important steps in the development toward perfect adaptation to living conditions mankind shares with preceding dominant forms of animal life.

The one thing man possesses that sets him above all other forms of living things is a development of the last few million years. It is his large brain, several times as large as was ever owned by any of his predecessors. Man shares with many lower forms of life the eyes, nervous system, digestive tract, muscles, backbone, lungs, warm blood, and capacity to bear living young. His large brain he shares with no other living thing. It is this which makes him "homo sapiens"—reasoning man—and which gives him his large degree of ability to compel all other living things and all the resources of nature to serve his welfare.

Mankind has been the dominant living creature for only a fraction of one per cent of the billion years of history that we can read. If we interpret the past eras correctly man's period of dominance has just begun. In the past after a superior form of being was once developed, it maintained its supremacy for long geologic ages. Fishes were the

highest form of life for about one hundred and twenty-five millions of years. The dinosaurs, who succeeded them, prevailed over all living things for the next seventy-five million years. Then followed about one hundred million years during which the small-brained mammals were the highest forms. Now for perhaps five million years the one large-brained mammal, man, has dominated all living things.

If we can reason at all safely from these past events, we may predict with assurance that man will rule the earth for a hundred million years or perhaps many hundreds of millions. This prediction seems well warranted when we consider that none of man's predecessors were one-tenth so able as he to control their surroundings, to bend the forces and the resources of the earth to their service. Man dominated the earth before he learned much of what we call science. This last century of progress in science has multiplied his knowledge many fold and has still further increased the strength of his hold on the scepter of command over all other living things.

Men who have studied the long, steady course of evolution have sometimes indulged in speculation about what type of being might develop to wrest from man his control of the earth. But it is just as impossible for us to imagine that the course

of physical evolution will develop a race of beings superior to ourselves, as it would have been for the dinosaurs to imagine the development of their successors or for the highest forms of small-brained mammals to imagine the development of a race vastly superior to themselves in brain power. Our experience goes no higher than its own level as a basis for imagining the developments of the future. The one thing we recognize which preceding dominant living forms could not, is that there is a process of evolution constantly at work which has been operating for a billion years. The continuation of this process must undoubtedly result in developing man or some other form of life to still higher degrees of perfection. However, nothing on the farthest horizon of our scientific imaginings seems at all capable of threatening the supremacy of our race. The most probable expectation is that man will continue to improve until the still dominant human race of a hundred million years from now will be greatly superior to the race we know at present. The detail of the ways in which this race will be superior to ours I leave to your own imagination. Your imaginings will be just as valid as my own.

With this long prospect of supremacy before us it is worth our while to look back over the long past and consider the continuously operating fac-

tors we there see which will play important parts in influencing the future of our race. Some of them are favorable and some are unfavorable.

One of the most important factors is the size of the land areas suitable for human habitation. We know that this has changed greatly in the past, and all evidence leads us to believe that the process of change will continue far into the future. Lands will slowly sink beneath the sea and slowly rise again. But lands in the past have always been of ample area, and there is no likelihood that in the future they will be so materially diminished in size as to threaten seriously man's continued existence. This factor must therefore be considered as favorable.

A second important factor in man's future is climate. We have seen that great variety has been characteristic of the long eras of the past. Glacial epochs have at times covered great areas with inhospitable ice. At other times there have been periods of zonal climate such as we have today, varying from tropical to frigid. During most of the long record, however, indications are that heat was better distributed than today and semi-tropical climate prevailed over the whole earth. Desert and well-watered conditions have existed in various parts of the earth throughout the whole billion years we have studied. The

most important observation we have been able to make on past climates is that there has been no time in which the whole world has suffered from climatic conditions unfavorable to the continued existence of living things. With this long period to guide us we are justified in looking forward to a long future of climatic conditions equally favorable.

The climatic conditions under which the human race has developed are those of unusual cold, as compared with climates of past ages. Man has made most progress in regions where he has had cold to fight against. In tropical climates he has retained his primitive, uncivilized methods of life and has not made much progress. Life there, apparently, is too easy to stimulate him. The question then arises as to the effect of the warmer climates that will return in the distant future. Will the whole race deteriorate and revert to primitive methods of easy living, or will man's increase in knowledge enable him to combat successfully the enervating effect of these softer conditions? The factor of climate may be considered as doubtful in its effect on the future of the race, but fortunately this doubt need not alarm us, as changes are bound to be too slow to affect the next few thousand years.

There is another factor, however, which is distinctly unfavorable in a way that seriously

threatens immediately following generations. It is the rapidity with which we are using up the mineral resources on which our civilization is based. We can foresee the time, not millions, not even thousands of years ahead, but only centuries or even decades hence, when we shall have used up the available mineral fuels and the ores of metals. The probable effect of this shortage on the lives of our great-grandchildren is not hard to predict. If their lives are to go on in the enjoyment of all the facilities we have at present, science and industry must discover ways of using natural energy from other sources, such as solar heat, of which there is, fortunately, a superabundance for all our power needs. New ways must be found of getting metals cheaply from sources too low in grade to be used in our present processes of metal extraction. If these things are not done, our immediate descendants must learn to live with much less of mechanical power and metals. Whether this will mean a return to conditions which prevailed a century or two ago—whether the civilization of future times will be obliged in large measure to do without the transportation facilities and the power we now enjoy—remains to be seen. Personally I have confidence that it lies within the intelligence of the race to solve these problems satisfactorily; that man will go on steadily to the enjoyment, in

increasing degree, of the things that make our mode of living so much better than that of our great-grandfathers. Some one has truly said that a problem once recognized is half solved. Let us believe, then, that this unfavorable factor in the future of the race is far from being a hopeless one.

Because of the abundance of fertile soil in the United States we have not felt obliged to be careful in our use of this vital natural resource. But if we continue our present wasteful practice in using our soil, its capacity to furnish us food and clothing will be seriously diminished in a few generations. Already we find exhausted soil in some of the eastern states of the Mississippi valley. Farms that once were richly productive are no longer so fertile as they were a hundred years ago. Erosion has been allowed to wash thousands of acres into the streams, thus destroying them forever. The factor of continued soil productivity in the United States is therefore one which at present is decidedly unfavorable to our future welfare, but it is almost a certainty that this will be remedied within a short time.

All these factors we have been considering, you will note, are material or physical in character. They concern the continued capacity of the earth to support the race in large numbers, as at present, and to supply the things necessary for our physical

existence. In general, the present state of our knowledge warrants a confident expectation that man will find sufficient to supply the bare necessities for his continued existence. It also warrants a strong hope that his ability will enable him to find, in addition to bare necessities, all the material things that he needs to continue his present high state of civilization far into the future, for a period measured in geological epochs rather than in hundreds or thousand of years.

It is when we turn from the supplies of material things to the things within man's own make-up that we find the most important and most doubtful factors which affect the future success of our race. Here we must depart for a moment from the domain of geology to sketch our picture of the future.

Our progress in the physical sciences, in the mastery of the material things of the earth, has been vastly greater in the last century than in all preceding human history. But in the science of right conduct and character, known as ethics, in the doctrine of man's duty in respect to himself and to the rights of others, we have progressed little if any beyond our recent ancestors. In both mental and moral qualities we are not materially different from them. Notwithstanding this lack of progress in these highly important qualities, we are called upon today to operate an unprece-

dentedly complex civilization, with production, distribution, consumption, finance, credit, and all human relations on a scale incomparably more vast and confusing than ever before. These new complexities demand both greater intelligence and the acceptance, by every good citizen, of moral responsibilities of far broader scope than were demanded of any previous generation. Scientific progress has been the result of the efforts of a relatively few thousand scientific and inventive minds. Its benefits and the attendant responsibilities are spread among the millions. The designing and making of a modern automobile requires rare brains, but any moron can drive one and kill people with it.

The remarkable thing, it seems to me, is not that our race has bungled in many ways in its handling of these new facilities developed by the last century of progress in science, but rather that it has had intelligence and ethical responsibility enough to bungle so little as it has. The use that will be made of the tools provided by modern science when they get into the hands of the more ignorant and uncivilized portions of the human race is an ethical question that we cannot answer. Will these groups be able to withstand the temptation to use selfishly and unwisely the power so given them?

Another question of the centuries immediately before us relates to those who are mentally deficient, and to the unsocial, anti-social, and criminal groups, who now make up too large a proportion of mankind and whom most intelligent people at present consider subnormal. Our criminal procedure and our method of dealing with the mentally and morally deficient are based on a gospel of pity for the individual and on a recognition of individual rights rather than on a gospel of race welfare. We aid and assist the subnormal to exist. To these subnormal people public opinion grants the right to propagate their kind equally with those we consider good citizens. What will our race be like a hundred thousand or a few million years from now? Will the race be better on the average, shall we have learned to suppress those tendencies to short-sighted selfishness that tempt all of us to "take the cash and let the credit go," or will the race be worse than at present? Shall we have developed to the point where each man accepts willingly *his full share* of the responsibility for the welfare of the whole race? Upon the answer to this hangs all the future of mankind.

To conclude this discussion, let us return to geology once more. There are two great lessons that geology teaches. One is that the evolutionary process goes on without stop. The other

is that time, as measured by our brief standards, is endless. Life upon the earth has endured for more than a billion years in the past and has, so far as we can foresee, an equally long period before it. The generations of the past have increased the knowledge and power of our race and have handed the augmented heritage on to us. In the grand drama of the evolution of the race we who live today have vital parts to play. We are the links between the past of the race and its future. Will the racial heritage we pass on to succeeding generations be still further augmented or will it be diminished? If we build for better things, for a better race to come, we shall have done our bit in the long, slow progress toward a perfection not yet attained but toward which all mankind looks with longing.

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